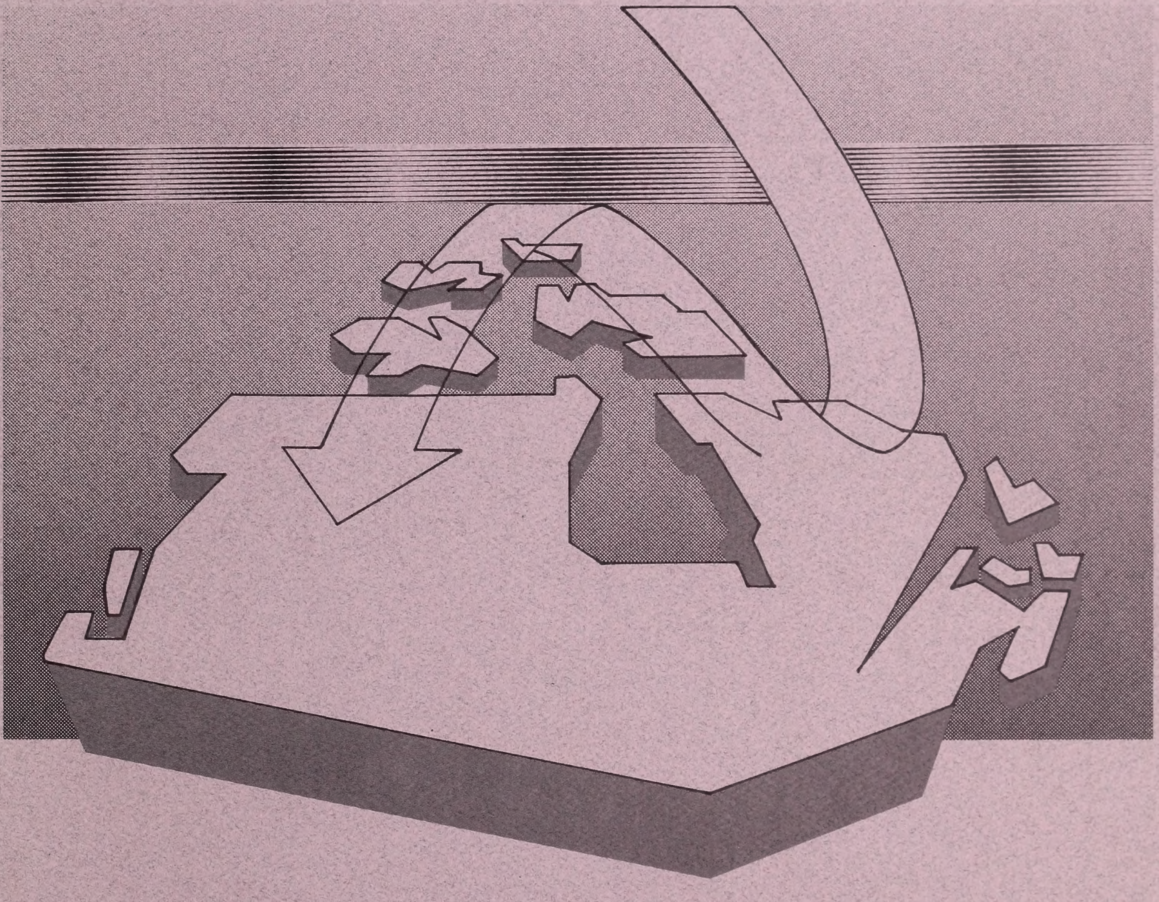
# CLIMATE WARMING?

## EXPLORING THE ANSWERS





ENVIRONMENT COUNCIL OF ALBERTA

# Climate Warming? Exploring The Answers

A Staff Report
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## ACKNOWLEDGEMENTS

We are pleased to make this paper available as a public service. Its primary purpose is to increase awareness and understanding of global warming. Climate affects our lives in innumerable ways and changes in climate will have important implications for our environment, our economy, and our quality of life.

Scientists around the world are daily improving human understanding of climate change and its consequences. Meanwhile, policy analysts and environmentalists are using the information to develop ideas for actions, and politicians and government staff are meeting to develop regional, national, and global response strategies. This report presents the essential elements of the climate change issue in a short and understandable manner.

In preparing the paper, we received help from many individuals. We would like to express our sincere appreciation to all who reviewed this paper and provided useful comments, suggestions, and additional information. Thanks are due to Alberta Environment, Alberta Energy, Alberta Agriculture, and Alberta Forestry, Lands and Wildlife for their reviews and most helpful suggestions.

As well, the paper benefitted from comments provided by Teja Singh, Forestry Canada, Tim Goos, Environment Canada, Peter Mahaffy and John Wood, The King's College, and Lawrence Nkemdirim, University of Calgary.

The style and readability of the paper have been greatly influenced by the work of the Environment Council of Alberta's editor, Elizabeth Alke. Her editing of this paper has made the information about climate change accessible to a wide readership. We also extend our thanks to other staff of the Environment Council who made this paper possible and assisted with reviews, typing, and information collection. The final content of the paper owes much to the input of all these people, but we bear responsibility for any inaccuracies and for the views expressed.

John Lilley
Calvin Webb

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## Chapter One

# Introduction

There is general agreement that humans should reduce the impact of their activities on the environment, including those activities that result in emission of greenhouse gases. This consensus reflects growing awareness that increased concentrations of these gases in the atmosphere will cause the earth's climate to warm.

Computer programs are being used to model the response of climate to changes in concentrations of greenhouse gases. Along with the results of scientific observations, data from climate models show that past emissions of greenhouse gases have probably committed the earth to some degree of climate warming. Computer models also indicate that, within less than a century, the world could have a climate different from that ever experienced by human beings.

A warmer climate would affect all natural resource industries including agriculture, forestry, tourism, and recreation. While there is no clear evidence that this change is upon us, the potential consequences of a few degrees increase in average global temperature point to the need for action even as we continue gathering evidence of climate change.

Around the globe, across Canada, and within Alberta, extensive research is underway to improve our understanding of climate change. At the same time, decision makers are discussing policies, programs, and actions that might be taken to address the matter of climate change. These proposed steps follow two courses: actions to reduce emissions and actions that could help Albertans adapt to a change in climate. Many of the proposed interventions make sense even if climate change does not unfold as projected.

The consumption of fossil fuels is an important cause of climate warming, and changing fuel consumption habits offers the best opportunity for reducing emissions. Because Alberta's economy depends in large part on the extraction and sale of fossil fuels (75 percent of these fuels are sold outside the province), any actions affecting the fossil fuel industry will affect all Albertans.

Albertans will be caught in the spreading wave of responses to climate change. Its social, economic, and environmental implications demand that we become aware of the issues and involve ourselves in shaping Alberta's response. The overall purpose of this report, therefore, is to deliver a general understanding of climate change and provide background and context for discussion of this complex issue.

The authors of *Climate Warming? Exploring The Answers* hope that this publication will prove to be a valuable supplement to the publications that Alberta Energy and Alberta Environment are currently developing.

Albertans who read these documents will be better prepared to participate in current efforts to develop a provincial Clean Air Strategy. This strategy will deal with energy-related emissions that contribute to acid rain, smog, and the greenhouse effect. It will also provide concrete recommendations for action.

## SCOPE

As the title of this report, *Climate Warming? Exploring The Answers*, indicates, there is uncertainty about whether the earth's atmosphere is indeed warming. This report explores these uncertainties. It also assumes that the consequences of climatic change warrant exploration of what Albertans might do to both reduce the causes and adapt to a changing climate.

Climate change is a very complex topic. Even the brightest scientists, helped by state-of-the-art computers, are still learning about what happens in the earth's atmosphere as a result of the injection of greenhouse gases. Books and papers by the hundreds have been written about climate change. This short paper can only give an overview of the subject, its implications, and possible solutions.

## CONTENTS

This paper delves into a number of topics. It discusses the physics and chemistry of greenhouse gases, the role of greenhouse gases in climate change, and human health concerns about ozone. It also examines the specifics of how greenhouse gases affect climate, provides a general discussion of the implications of climate change, and discusses strategies to both reduce the speed of change and help Albertans prepare for climate warming.

Some of the information contained in Chapter Two, Dynamics of Greenhouse Warming, is technical and scientific. It is not essential reading, but it describes the way greenhouse gases work and the consequences of the buildup of greenhouse gases in the atmosphere. This information will help readers understand the problem of climate warming and the potential of various response strategies. Chapter Three provides information about the sources of the most important of these gases and why observed increases have created concern about climate warming.

The implications of ozone depletion caused by chlorofluorocarbons (CFCs) are described separately in Chapter Four. The present concern about CFCs and the drive to control them relates to the way in which CFCs contribute to increased ultraviolet (UV) radiation at the earth's surface. With this treatment of greenhouse gases in place, Chapter Five outlines what some of the environmental and economic consequences of climate change could be.

Many of the consequences of climate change scenarios — changing distribution of forests, shifts in agricultural production patterns, extinction of species — have received substantial media coverage. These scenarios are based on the projections of computer models. However, the limitations of these computer models give rise to debate about climate change and its effects. Chapter Six discusses computer models and presents evidence for and against climate change.

To appreciate the scope, complexity and uncertainty of climate change scenarios, both chapters Five and Six should be read together. The authors of this report hope that the discussion in chapters One through Six demonstrates that the greenhouse effect hypothesis is a plausible one and that the possible consequences cannot be ignored. Chapters Seven through Thirteen discuss what measures might be taken to address the problem.

Strategies to deal with climate change are needed. They should respond to the weaknesses in our understanding of climate change, the need to reduce emissions, and the possibility of adapting to projected climate change. While this report does not develop response strategies, it attempts to provide enough information for readers to develop their own ideas, suggestions, and answers. The authors of this report encourage readers to make their views known through participation in ongoing discussions about the potential problem of climate warming.

Chapter Two

# Dynamics of Greenhouse Warming

## THE ATMOSPHERE

Life on earth depends on the atmosphere: the gaseous envelope that surrounds the earth. The atmosphere provides us with the air we breathe; its gases retain the heat that warms the earth; and the protective layer of ozone in the atmosphere shields us from damaging rays emitted by the sun. The atmosphere also acts as a reservoir for natural substances as well as emissions derived from human activities. Within this reservoir physical and chemical actions and reactions take place. The results determine weather systems and shape the earth's climate.

The atmosphere extends a few hundred kilometres above the earth and can be divided into several layers based mainly on temperature. Two atmospheric regions nearest the earth's surface, the troposphere and the stratosphere, are of particular importance in this study of climate change.

The troposphere is closest to the earth. It extends out about 8 to 17 kilometres above the earth's surface and is thickest at the equator. Temperatures in the troposphere generally decrease as altitude increases. They are warmer nearest the earth, in part, because gases in the troposphere are warmed by heat radiated from the earth.

The stratosphere extends out, beyond the troposphere, to about 50 kilometres above the earth. Gases in the stratosphere are heated mainly by incoming radiation from the sun; and temperatures in the stratosphere increase as altitude increases.

As a consequence of the temperature differences between the troposphere and the stratosphere, and the resulting air circulation patterns, exchange of air between the two regions is quite slow.

### Composition

Dry air near the earth's surface consists mainly of nitrogen (78.1 percent by volume) and oxygen (20.9 percent by volume) with a small amount of argon (0.9 percent) and carbon dioxide (0.03 percent). Air in the troposphere also contains small amounts of methane, nitrous oxide, carbon monoxide, hydrogen, and ozone as well as other gases such as chlorofluorocarbons (CFCs) that are of strictly human origin. Near the earth's surface, water vapor comprises up to 4 percent of the atmosphere by volume.

## GREENHOUSE WARMING

Were there no carbon dioxide or water vapor or other greenhouse gases in the atmosphere, the earth would be a very cold place. Now there is concern over the possibility that increasing amounts of greenhouse gases in the atmosphere may heat the earth too much.

Both the life-permitting and life-threatening characteristics of the atmosphere result from the *greenhouse properties* of some gases. These gases allow sunlight to pass through them, but they retard the flow of resultant heat from the earth's surface back into the outer atmosphere.

## Electromagnetic Radiation

A brief description of electromagnetic radiation and earth's energy balance is essential to understanding natural greenhouse warming and enhanced warming due to human activities.[1]

We are surrounded by electromagnetic radiation, of which light and radio waves are just different forms. Physicists apply different names to electromagnetic radiation according to the frequency or wavelength of a particular form of energy. The electromagnetic spectrum (Figure 1) extends from short wavelength cosmic and gamma rays, through medium wavelength visible light, to long wavelength radio waves. Shortwave radiation has high frequencies and high energy; longwave radiation has low frequencies and low energy. Wavelengths, from gamma waves to radio waves, extend from a very small fraction of a micron (1 micron equals a millionth of a metre) to several million microns (several metres).

The wavelength and intensity of radiation emitted from an object depends upon its temperature. Any object with a temperature above absolute zero (-273 degrees Celsius) will emit radiation in the infrared part of the spectrum. If an object is hot enough, it will also emit radiation in the visible light, and possibly even in the ultraviolet-light, portion of the electromagnetic spectrum. Short wavelength radiation is emitted at high temperatures; long wavelength radiation occurs at lower temperatures. Consequently, the radiation from a very hot object like the sun is, relatively speaking, shortwave. Solar radiation ranges in wavelength from 0.2 to 4.0 microns and beyond in small amounts; but the solar energy curve peaks around 0.48 microns in the visible part of the electromagnetic spectrum.

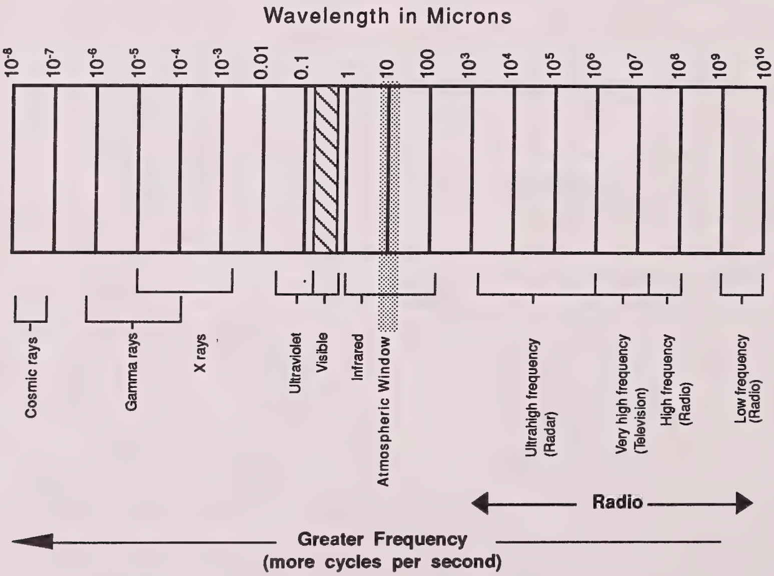
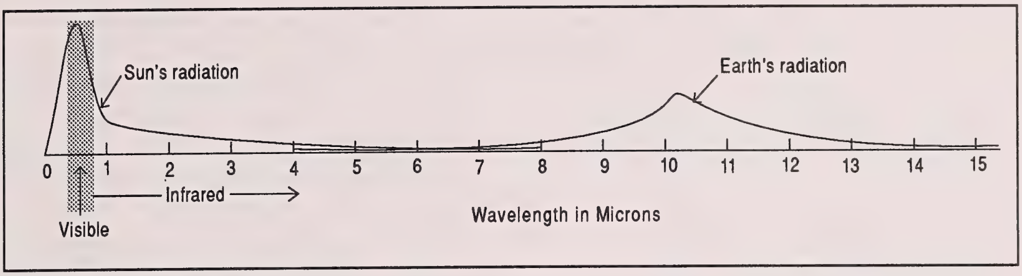



**Figure 1: The Electromagnetic Spectrum**
Source: After Seinfeld (1975)

1 The information in the next few pages is drawn from the following sources: Gates 1962; Budyko 1974; Seinfeld 1975; Barry and Chorley 1976; McElroy 1988; Kasting et al. 1988.




Energy radiated from the earth is much weaker than the sun's radiation. The strength of the earth's radiation has been greatly exaggerated in this graph to allow comparison with some features of the radiation spectrum of the sun.

**Figure 2: Radiation Spectra of the Earth and Sun**
Source: After Foster (1982)

The energy radiated from the relatively cool surface of the earth is longwave, ranging from 4 to 100 microns. This energy peaks at wavelengths of around 10 microns. These wavelengths are within the invisible, infrared portion of the electromagnetic spectrum. Figure 2 shows the wavelength range of both direct solar energy and energy radiated from the earth.

Gases absorb energy of specific wavelengths. Water vapor and carbon dioxide and other gases in the earth's atmosphere are strong absorbers of infrared radiation. For example, water vapor — a greenhouse gas that is important for keeping the earth warm — strongly absorbs radiation with wavelengths between 5.3 and 7.8 microns. Carbon dioxide strongly absorbs infrared radiation that has wavelengths of 4.3 microns and 13.5 to 16 microns.

Figure 3 shows how efficiently water ($H_2O$), carbon dioxide ($CO_2$), and ozone ($O_3$) absorb or transmit radiation over a small portion of the infrared wavelengths. This figure also illustrates that the most abundant gases are not very effective at absorbing infrared radiation with wavelengths between 8 and 13 microns. This wavelength range is often called the *atmospheric window*.

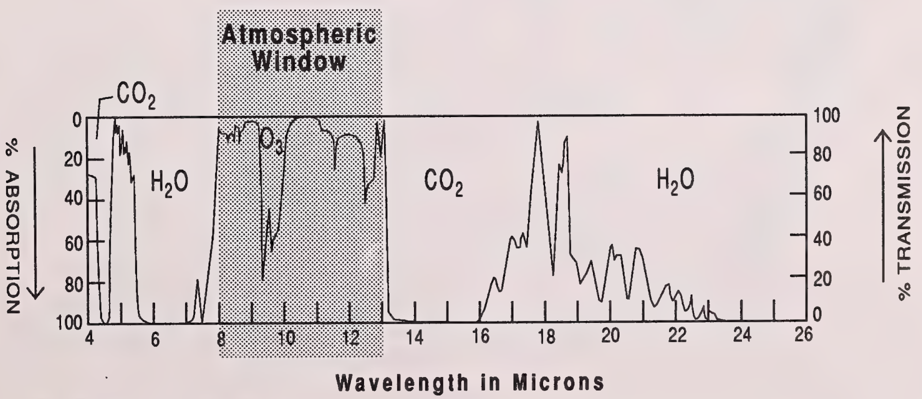



**Figure 3: Absorption of Radiation by Greenhouse Gases**
Source: After Gates (1962)

Other gases that have greenhouse properties do absorb infrared radiation with wavelengths in the atmospheric window. Increases of these greenhouse gases in the atmosphere may, therefore, cause more warming than increases in carbon dioxide.

## Earth's Energy Balance

The energy absorbed by various gases in the atmosphere is ultimately re-radiated back to outer space or to the earth's surface. The actual amount of absorption and re-radiation in the atmosphere is quite complicated; it varies with the distribution of gases at different levels of the atmosphere, where there are large differences in temperature and pressure.

Figure 4 shows recognizable pathways of energy in the earth's atmosphere. It also gives some perspective on the importance of greenhouse gases. The relative quantities of energy on the different pathways are only approximations; these numbers represent averages over the whole earth. Each unit equates to 2.63 kilocalories per square centimetre per year of incoming solar radiation received at the top of the atmosphere.

From Figure 4 you can see that the outer edges of the earth's atmosphere receive 100 units of solar radiation. The *albedo*, or reflective ability of the earth and its atmosphere, immediately reflect about 30 of the 100 units of incoming radiation into outer space; 25 units are reflected by the atmosphere and 5 units are reflected by the earth's surface. This energy is not available to heat the earth's surface or its atmosphere.

Water vapor, dust, carbon dioxide, and water droplets in clouds absorb 25 of the 70 units of solar energy that do enter the atmosphere. Forty-five percent of incoming solar energy is absorbed by the earth's surface. The earth's surface and the atmosphere absorb this shortwave light (primarily ultraviolet (UV), visible, and infrared) energy and are warmed by it.

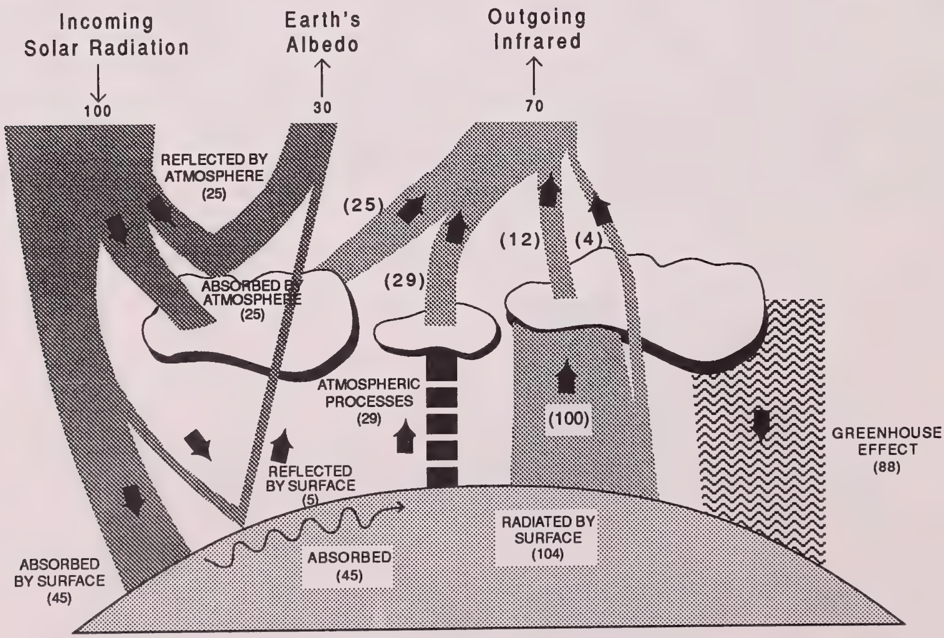



**Figure 4: Earth's Energy Balance**
Source: After Schneider (1987, 1989a, 1989b)

Figure 4 shows that the atmosphere is mainly heated from below. It also shows that the amount of energy leaving the earth equals the amount absorbed by the earth's surface and the atmosphere (70 units). Without this balance the earth would have burned up long ago.

## The Significance of Greenhouse Gases

Most of the energy that is lost from the atmosphere to outer space comes from three sources:

- the incoming solar energy absorbed by the atmosphere and clouds,
- radiative heat loss from the earth's surface, and
- atmospheric processes such as evaporation and conduction (sensible heat transfer) from the earth's surface.

Only 4 units of this outgoing energy escapes directly, much of it escapes through the atmospheric window (see Figure 3).

Because of their heat-trapping ability, the greenhouse properties of the atmosphere play a very significant role in the dynamics of the earth's climate. Figure 4 shows that 88 units of longwave infrared energy, about twice the amount absorbed from the sun at the earth's surface, are radiated back to the earth's surface through greenhouse processes.

Scientists estimate that the processes of absorption and re-radiation of energy by greenhouse gases are responsible for warming the earth's atmosphere about 35 degrees Celsius more than would be the case without them.

As various human activities pump more gases with greenhouse properties into the atmosphere, scientists, and others are becoming concerned that the atmosphere will warm considerably. Warmer temperatures might cause unwanted environmental effects:

- disruption of precipitation patterns, which might result in higher frequency of droughts in susceptible regions and increased occurrence and severity of floods in others,
- a rise in sea level and the loss of valuable coastal, agricultural, and recreational land,
- a higher frequency of severe storms and an increase in the intensity of those that are thermally driven,
- shifts in vegetation zones, including a poleward retreat of the boreal forest,
- decreases in plant and animal productivity, in both natural and agricultural systems,
- strains on the forest and agricultural industries, and
- weakening of ecological food chains or decreases in biological diversity.

Many people are not aware, however, that some positive results may also occur from climate warming. These benefits include growing season enhancement, reduction of fossil fuel demand, stimulation of research into new crop varieties, and aggressive conservation initiatives, such as reforestation and improved efficiency of resource use.

There may even be another side benefit to the problems posed by climate change; nations that strive to address these problems may establish new precedents for cooperation. Whether or not Albertans experience the negative impacts or positive opportunities that result from climate warming, they will be required to change the ways they do things. Understandably, these changes will be uncomfortable for some.

Chapter Three

# The Greenhouse Gases

Only a small amount of gas, much less than one percent of that in the atmosphere, is responsible for natural and potential humanly induced atmospheric warming. The low concentrations of greenhouse gases in the atmosphere mean that they are easily changed in relative amounts. This characteristic and the high efficiency with which some of the gases trap infrared radiation cause scientists to be concerned about the buildup of greenhouse gases in the atmosphere.

## CARBON DIOXIDE

Most public discussion about the greenhouse effect centres on carbon dioxide. It is present in concentrations of about 350 parts per million by volume (ppmv) and is increasing by about 0.4 percent each year. By the year 2030, carbon dioxide is expected to account for about half the greenhouse warming that occurs (Figure 5).

Concentrations of carbon dioxide in the atmosphere have increased from concentrations of 280 ppmv since the mid 1700s to today's 350 ppmv. The timing of these increases suggests that they are at least partly due to the consumption of fossil fuels spurred by the Industrial Revolution.

Figure 6 shows only the trend in rising carbon dioxide concentrations since 1958. The presence of similar levels of this gas in three disparate locations within the Northern Hemisphere, including a data point from Fortress

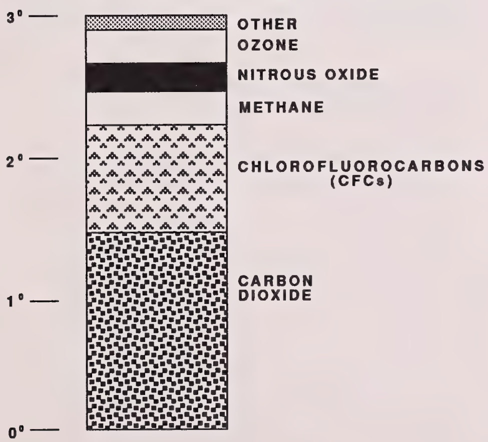



**Figure 5: Relative Contribution of Greenhouse Gases to a Temperature Increase of 3° Celsius**
Source: After Environment Canada (1986)

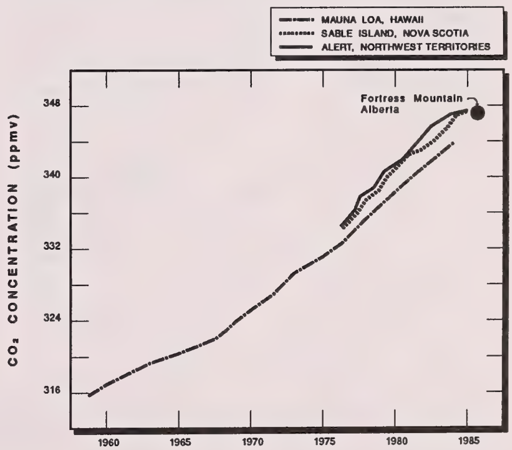



**Figure 6: Increases in Carbon Dioxide 1958-1985**
Source: After Daniel (1988)

Mountain in Alberta, demonstrates that carbon dioxide is well mixed in the atmosphere. These measurements also show that increases in carbon dioxide are real.

## The Carbon Cycle

There is a finite amount of carbon on the earth and in the surrounding atmosphere. It is found in the atmosphere, vegetation, the ocean, sedimentary rocks, and hydrocarbon fuels, all of which are referred to as carbon *sinks*. At different stages in the carbon cycle carbon dioxide is released. When this happens carbon *sinks* become carbon *sources*. A balance of sorts between carbon storage and carbon dioxide release is essential to maintaining a habitable environment for most organisms.

Plants act as carbon sinks because they normally use more carbon dioxide in the photosynthetic process than they release when they respire (access energy from food). Respiration is also said to occur when plants and animals die and decay, releasing carbon dioxide.

Respiration annually releases about 100 billion tonnes of carbon. Releases of carbon dioxide that are wholly or partially attributed to human activity include fire, mostly from tropical woodlands and savannas (2 to 5 billion tonnes of carbon annually) and burning fossil fuels (about 5 billion tonnes of carbon annually).

The amount of carbon dioxide tied up in other blocks of the carbon cycle — sedimentary rocks, fossil fuels, and water — far exceeds that in vegetation (Berner and Lasaga 1989). But more is probably known about carbon dioxide exchange and storage in land-based ecosystems than other large components of the carbon cycle. For this reason, discussions about increased carbon dioxide in the atmosphere tend to focus on land-based ecosystems.

Human modifications of the earth's land-based ecosystems, such as deforestation, have reduced the ability of these components of the carbon cycle to act as carbon sinks. To the amount by which their carbon uptake is reduced, these ecosystems can be thought of as carbon sources. One estimate placed the net annual release of carbon dioxide to the atmosphere due to recent changes in the earth's ecosystems at 1.6 billion tonnes. That figure represents about a third of the carbon dioxide released by fossil fuel burning (Mooney et al. 1987).

## METHANE

Methane concentrations in the atmosphere have doubled over the past 200 to 300 years to present-day levels of 1.7 ppmv. Concentrations are rising at a rate of one percent annually, about two and a half times the rate of carbon dioxide. This is a relatively rapid rate of increase, and methane is from 20 to 25 times more effective than carbon dioxide as a greenhouse gas. The combination of these factors indicates that methane will be an important greenhouse gas.

Part of the reason why methane and other trace gases are so effective at trapping infrared radiation is that carbon dioxide concentrations are close to a saturation point of sorts. The large mass of carbon dioxide in the atmosphere means each incremental increase in carbon dioxide is less effective as an energy absorber. Larger quan-

**Table 1: Methane Sources**

**The total amount of methane released into the atmosphere each year is between 400 and 650 million tonnes.**

| Source | Million Tonnes |
|---|---|
| Natural Wetlands | 100 - 150 [1] |
| Rice Paddies | 35 - 170 |
| Grazing Animals (Ruminants) | 60 - 200 [2] |
| Termites | 15 - 150 |
| Solid Waste Landfills | 70 |

[1] Half of the methane that originates in natural wetlands comes from organic, rich arctic soils and boreal wetlands.

[2] The amounts of methane released by ruminants represent a fourfold increase since 1890.

tities of this gas are needed to absorb similar amounts of infrared energy.

Gases in lower concentrations, for example, methane, are still very effective. They also tend to absorb radiation in the atmospheric window region, where less longwave radiation is currently absorbed than elsewhere in the electromagnetic spectrum. Some of the gases are more efficient at absorbing longwave radiation than carbon dioxide; they have stronger *absorption band strengths.*

While increases in sources of methane as a result of global expansion of agriculture may be responsible for rapid increases in atmospheric methane, changes to methane sinks may be more important.

The annual burning of grasslands, a common feature of farming in Australia and parts of Africa, offers one example of a methane sink that is being altered. The dryland soils in these areas are normally an important sink for methane. Changes in the activity of soil microbes as a result of burning grasslands could be responsible for extra amounts of methane in the air. Nitrogen fertilizers and the nitrogen that enters the soil as a result of acid rain are also thought to have reduced the ability of soils to act as methane sinks.

Changes in the atmosphere are also important in accounting for the rise in atmospheric concentrations of methane, because most methane destruction probably occurs in the atmosphere. Very reactive hydroxyl radicals, created after ultraviolet (UV) light breaks apart ozone, remove pollutants like methane from the atmosphere. There has, however, been a large reduction (about 25 percent) in the amount of hydroxyl radicals in the atmosphere over the past 40 years. Apparently, the hydroxyl cleansing system is too overloaded with carbon monoxide, from sources like vehicle exhaust, to remove methane.

Presently, 50 million tonnes more methane enters the atmosphere than leaves it; and the injected methane remains about ten years in the atmosphere (Pearce 1989b; Mooney et al. 1987; Blake and Rowland 1988; Khalil and Rasmussen 1990; McElroy 1988; Steudler et al. 1989).

## NITROUS OXIDE

Nitrous oxide is present in the atmosphere at concentrations of about 300 parts per billion by volume. Concentrations are increasing about 0.2 percent annually.

Nitrous oxide is formed by soil- and water-based microbes in those parts of the nitrogen cycle that result in the conversion of inorganic nitrogen into gaseous nitrogen. The production of nitrous oxide from nitrates (the nitrate form of nitrogen) is most rapid in anaerobic soils (soils that lack oxygen) and in anaerobic pockets within aerobic soils.

The production and subsequent soil application of nitrogen fertilizers, which are applied as or converted to nitrate, supplement naturally produced nitrates. They may thus be a source of increasing amounts of nitrous oxide in the atmosphere. Most of the increase in nitrous oxide concentrations, however, is from combustion of biomass (vegetation) and fossil fuels. The reaction between nitrous oxide and activated oxygen in the stratosphere is the major known sink for nitrous oxide. This reaction may also contribute to ozone depletion (Mooney et al. 1987; Environment Canada 1986).

## OZONE AND CHLOROFLUOROCARBONS

Ozone has an average concentration in the atmosphere of less than 1 part per million by volume. The highest concentrations of ozone, up to 6 ppmv, are found in the stratosphere; the troposphere normally has about 0.03 ppmv. Average concentrations in Alberta are near the 0.03 ppmv value (Angle and Sandhu 1989; Peale and Fong 1990). Ozone is a boon or bane depending on its concentration and location. In the stratosphere ozone's ability to absorb UV light from the sun is critically important to life on the earth's surface. In the troposphere ozone is a pollutant.

Unfortunately, human activities are changing both the location and concentration levels of ozone and causing a variety of problems:

- Chemical reactions involving small amounts of chlorofluorocarbons (CFCs) are depleting ozone in the stratosphere. This depletion is creating the ozone hole, which allows more UV radiation to enter the troposphere and reach the earth's surface.
- Increased UV radiation at the earth's surface may cause increases in skin cancers.
- Increased levels of UV radiation may accelerate the chemical reactions that produce ozone in the troposphere (Moore 1989).
- Pollutants, nitrogen oxides and volatile organic compounds (VOCs), generated by automotive and industrial emissions in the troposphere are reacting to produce ozone.
- Increases in ozone within the troposphere have the potential of causing damage to vegetation and human respiratory organs (Monastersky 1989c; Bates 1989; Environment Canada 1986).
- In addition to causing health detriments, increased concentrations of ozone in the troposphere could cause warmer tropospheric temperatures. However, the influence of other greenhouse gases, the amount of ozone depletion in the stratosphere, and the altitude at which it occurs, will determine how temperatures change (Ramananthan et al. 1985; Ramananthan 1988; Miller and Mintzer 1986).

CFCs are present in the atmosphere in small concentrations. The two most important greenhouse CFCs, CFC-11 (used as foam blowers) and CFC-12 (refrigerants), are present in concentrations of about 0.2 and 0.3 ppbv. The small concentrations belie their importance as greenhouse gases. CFCs are up to 10,000 more effective on a molecule-to-molecule basis than carbon dioxide at absorbing longwave infrared radiation. Also, they are increasing at about 6 percent a year, about 15 times as fast as carbon dioxide (Evans 1988; Bolle et al. 1986; Hammitt et al. 1987).

Collectively, CFCs are next in importance to carbon dioxide in terms of potential greenhouse effect over the next few decades (Ramananthan et al. 1985). At present, most of the public and scientific discussion about CFCs focuses on the role they play in depleting ozone in the stratosphere.

Chapter Four

# Ozone Depletion: Consequences and Causes

Changes in ozone concentrations in the atmosphere, especially the stratosphere, will not only affect world temperatures, but the quality of sunlight received at the earth's surface. Ozone strongly absorbs shortwave, high-energy ultraviolet (UV) radiation from the sun. By doing so, ozone protects living organisms on the earth's surface from harmful UV radiation. However, the amount of ozone in the stratosphere, where most of the absorption of harmful sunlight takes place, is decreasing.

The depletion of ozone in the stratosphere is strongest at high latitudes in late winter, early spring. The depletions over the Antarctic and, to a lesser degree, over the Arctic are significant enough to have been termed *ozone holes*.

Ozone depletion occurs beyond these regions as well. Recent estimates put the yearly average decrease of ozone in the stratosphere between latitude 53 degrees North and 53 degrees South at about 0.35 percent per year and a total decrease of 2.5 percent between the years 1978 and 1985. Measured losses have been greater in the Southern Hemisphere than in the Northern Hemisphere (Proffitt et al. 1989; Kerr 1988a; Bowman 1988).

## CONSEQUENCES OF OZONE DEPLETION

The anticipated consequences of greater exposure to UV light because of ozone losses include increases in skin cancer. Light-colored human skin efficiently absorbs light energy wavelengths near 0.3 microns in a region of the electromagnetic spectrum known as UV-B (biologically active ultraviolet light). This wavelength radiation breaks apart nucleic acids and proteins, the building blocks of living matter. This destruction is thought to impair the ability of cells to repair themselves or properly divide (Woods 1988; Shea 1988; Longstreth 1989). Decreases in ozone of 2.5 percent are expected to result in a 10 percent increase in the incidence of skin cancer (Kerr 1988a).

Some estimates have projected much greater reductions in stratospheric ozone than 2.5 percent and concurrent, disproportionately large increases in transmission of nucleic acid-damaging light (Rowland 1989; Miller and Mintzer 1986; Cicerone 1987; BioScience 1981). The negative effects of UV light on immunity systems (Longstreth 1989) or viral activity enhanced by exposure to UV light (Longstreth 1989; Kristoffer et al. 1988) could increase the spread of infectious diseases.

Albertans could be spared the worst impact of changes to the quality of light (increased UV radiation) that reaches the earth's surface for several reasons. Ozone at the poles and over the earth's northernmost (and southernmost) regions is thicker than it is at mid-latitudes and equatorial regions. Though ozone losses are most severe at the poles, they occur in late winter when sunlight is not very intense. The impact of small increases in UV radiation in winter is further mitigated by the fact that during this season people wear protective clothing and limit their outdoor activities. At mid- and equatorial latitudes, where the ozone layer is naturally thinner, more significant problems may occur as a result of lower summertime ozone levels (Evans 1988).

While the potential for direct human health effects as a result of ozone loss is large, the impact on ecosystems may be of greater consequence. Exposure to greater amounts of UV radiation reduces land and water plant productivity (Miller and Mintzer 1986; Shea 1988; Woods 1988; Worrest et al. 1989; Voytek 1990). This reduction may mean more food shortages or weakening of ecosystems throughout the world. Reductions in plant productivity would also mean less carbon dioxide uptake and enhanced greenhouse warming.

## CAUSES OF OZONE DEPLETION

Like greenhouse warming, atmospheric pollution is thought to be the reason for losses of ozone in the earth's stratosphere. A variety of pollutants and chemical pathways contribute to ozone loss (Cicerone 1987).

Most of scientists' concern is about chlorofluorocarbons (CFCs). These chemicals are noted for their stability and non-toxicity. They found widespread application in industry as propellants for aerosol sprays (before they were banned in many parts of the world in the late 1970s), cleaners for sensitive electronic circuitry, coolants for refrigerators and air conditioners, and foam blowers. Compounds similar to CFCs called halons, which are used as fire extinguishants, are also causing concern.

When molecules of CFCs reach the top of the stratosphere they are exposed to intense short wavelength sunlight. Then they break down into their constituent and reactive elements, notably chlorine. The presence of chlorine catalyses a series of chemical reactions that results in a decrease of ozone molecules. Figure 7 shows, in a very simplified way, the series of chemical reactions that scientists think are involved in ozone depletion.

The bottom half of Figure 7, labelled *Ozone Destruction* shows the conversion of ozone into two oxygen molecules. Chlorine speeds up the natural rate of ozone destruction so that ozone concentrations decrease.

Ozone depletion occurs in the stratosphere at altitudes from 16 to 20 kilometres. Recent detection of chlorine monoxides at these altitudes, when ozone holes are forming, has been termed *the smoking gun* — evidence that chlorine is destroying ozone. This evidence supports the theory that ozone depletion is chemically induced by the breakdown of CFCs.

The ozone holes that have been observed in the Antarctic and Arctic are the result of upper atmospheric circulations. These circulation patterns allow cold, stable air to form and remain stationary over the polar areas for long periods during the winter. These very cold upper atmospheric conditions permit the formation of ice clouds known as polar stratospheric clouds (PSCs), which assist the chemical reactions described in Figure 7.

Increasing amounts of methane in the troposphere mean that more methane enters the stratosphere. There it breaks down and produces the stratospheric water from which PSCs can form (Stolarski 1988; Blake and Rowland 1988; McElroy and Salawitch 1989; Hofman et al. 1989; Kerr 1989a).

At lower latitudes, ozone destruction may be enhanced differently. The upper atmospheric conditions at mid-latitudes and tropical regions are not so cold as to allow the formation of ice clouds. Instead, droplets of sulphuric acid and water may provide a surface for chemical reactions that convert harmless chlorine compounds into forms that destroy ozone. The sulphur in the atmosphere comes from both natural sources and human activities. Fortunately, it appears that the acid droplets are about ten times less efficient than PSCs as reaction surfaces (Monastersky 1988b).

Like debates about the greenhouse effect, there is some uncertainty about the cause-effect relationships of ozone depletion. Do recent trends, for example, merely reflect natural variability in atmospheric ozone concentrations?

***Stratospheric ozone is created and destroyed in a natural cycle that has been functioning in relative equilibrium for thousands of years. However, when incoming ultraviolet light encounters chlorofluorocarbons, which human activities have created and introduced into the atmosphere, chlorine is produced.***

***Each free chlorine atom is thought to be capable of destroying as many as 100,000 ozone molecules.***

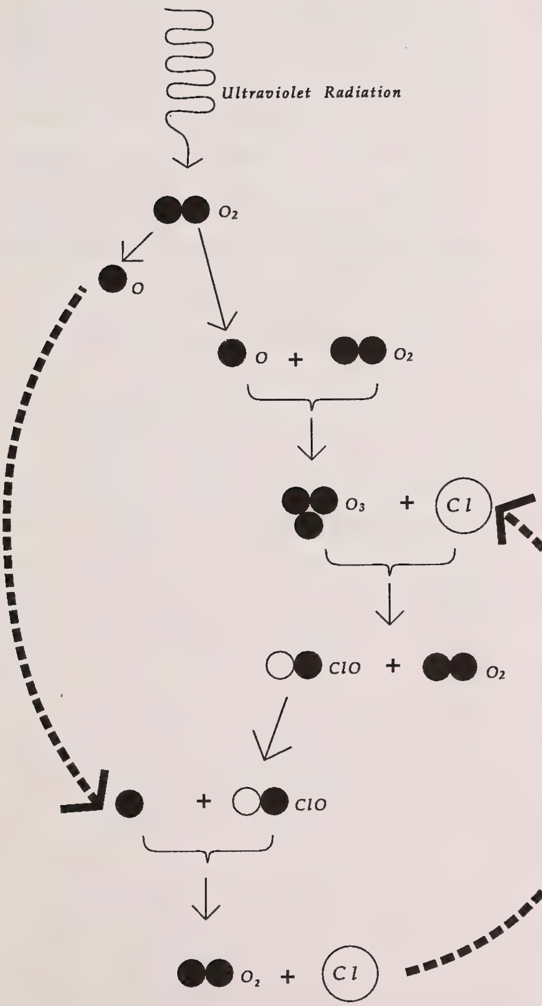



Figure 7: Ozone Chemistry in the Stratosphere

Source: After Moore (1989)

### *Ozone Creation*

*Ultraviolet light breaks apart an oxygen molecule ($O_2$) resulting in two free oxygen atoms.*

*An oxygen atom joins with an oxygen molecule and yields ozone ($O_3$).*

### *Ozone Destruction*

*Ozone reacts with a free chlorine atom (Cl) to form chlorine oxide (ClO) and oxygen.*

*Chlorine oxide reacts with a free oxygen atom to form a free chlorine atom and an oxygen molecule. The free chlorine atom is again available to break ozone apart.*

Present-day global ozone concentrations are comparable to low levels in the early 1960s (Bowman 1988). Ozone levels increased until about 1978; then they decreased. Some scientists believe that recent losses of ozone are within the range of natural variability and should not cause concern.

Sunspot cycles have been proposed as a cause of natural variations in ozone levels. There is supporting evidence for this hypothesis. However, very recent increases in stratospheric ozone during the current upswing in the sunspot cycle (since 1986) are viewed as only a reprieve by those who believe that CFCs are depleting ozone. Advocates of CFCs as the cause of ozone depletion predict that ozone levels will continue their downward trend again after 1991, when sunspot activity wanes (Kerr 1988c; Bowman 1988; MacKenzie 1988; Foukal 1990).

If CFCs are the cause of ozone losses, there are two features about the chemistry of CFCs about which we should all be concerned. The first is that in the processes depicted in Figure 7, the chlorine molecule is unchanged. Before it is inactivated or returned to the troposphere, each chlorine molecule can destroy 100,000 ozone molecules. Continued use of CFCs would maintain a ready supply of ozone-destroying chlorine molecules in the stratosphere.

The second important feature of CFC chemistry is that it takes decades for the CFCs to be broken down in the stratosphere. The CFCs may move up from the troposphere to the lower reaches of the stratosphere quickly; but air in the stratosphere is not turbulent. Therefore, CFC molecules take a long time to reach the top of the stratosphere where they break down. CFCs already in the atmosphere will deplete ozone for many years to come, whether or not human activities continue to inject more.

Chapter Five

# The Effects of Climate Change

Scientists predict that the greenhouse gases in the atmosphere will result in climate changes that have serious implications for our environment and the economic activities dependent on it.

## TEMPERATURE

Computer models are one of the tools that scientists use to assess climatic responses to changes in atmospheric greenhouse gas concentrations. The best of these computer models assess some changes in climate well, for example, temperature change. The temperature change predictions made by these computer models are based mostly on the doubling of carbon dioxide or its equivalent in all infrared gases including carbon dioxide. Anticipated increases in global average temperatures by about the year 2050 range between 1.5 and 5.5 degrees Celsius. Increases of between 3.5 and 5.0 degrees are thought to be most likely (Schneider 1989a and 1989b). Interesting geographical and seasonal trends are concealed by the averages.

Larger increases in temperature are anticipated at high latitudes, especially in the Northern Hemisphere. Northern areas including boreal Alberta could experience significant changes for several reasons:

- more frequent movement of air from lower latitudes into the boreal area,
- more cloud cover,
- thinning of ice (this would allow more heat from the water beneath the ice to enter the air above it),
- melting of ice in a warmer climate. Shorter seasons of ice and snow cover will decrease the albedo of the earth's surface and result in more absorption of heat (Goos: pers. comm.).

Increases of 12 degrees Celsius are possible, at least on a seasonal basis (Dickinson 1986; Pain 1988). Larger temperature increases are expected in winter than in summer; these temperature increases would probably result in longer spring and fall seasons.

A recent study on climate change in Alberta conducted by the Alberta Research Council (Wong et al. 1989) suggested that doubling carbon dioxide concentrations would cause average temperatures in Alberta to increase by 3 to 7 degrees Celsius. Greater increases could be expected in northern Alberta than in southern Alberta. Among the models used by the Research Council to assess climate change, there were differences in the months for which the greatest temperature increases could be expected.

Increases in air temperature could increase water loss by evaporation and by transpiration from plants. In turn, soils may be drier, and a northward shift in agricultural zones could result. Whether or not soil moisture deficits exist will depend, in a large part, on changes in precipitation resulting from climate warming.

## PRECIPITATION

The effect of doubled concentrations of greenhouse gases on precipitation is less certainly

predicted than temperature. In general, more humid and slightly wetter conditions are expected. Depending on location, decreases or increases in precipitation are possible. Furthermore, the timing of precipitation is likely to change because of reductions in thermal differences between the equator and the poles of the earth. Changes in wind and water currents will also affect the timing of precipitation (Mintzer 1988; Ramananthan 1988). Since winter temperatures are expected to rise dramatically, more wintertime precipitation may fall as rain and less as snow than is now the case.

The Alberta Research Council's studies suggested that Alberta's total annual precipitation could increase by as much as a third. The changed temperature and precipitation regime would give Alberta a climate similar to present-day Colorado (Wong et al. 1989). Changes in winter temperature and precipitation patterns would entail economic consequences for Alberta. Lamothe and Periard (1988) and Wall (1988), for example, anticipate negative effects on skiing in Quebec and Ontario. Similar consequences for the attractiveness of Alberta as a wintertime tourist destination may also be expected. Another possible consequence of temperature increase is that the demand for natural gas from Alberta may fall on a per capita basis because of reduced wintertime heating requirements (Acres 1989; Findlay and Spicer 1988; Goos 1989). There may also be a slight reduction in peak demand for electricity and, as a result, reduced costs for new generating capacity (Acres 1989).

Shifts in average precipitation are only part of the implications of climate change. Even small changes in the averages could result in pronounced increases in the frequency of extreme events. These extreme events could include periods of very high temperatures and drought, or very high rainfall. Many life-forms and economic sectors are more affected by changes in the frequencies of extreme events than changes in the averages. Gradual changes can be buffered by social mechanisms, and adaptations are also possible. The effects of extreme events are, however, difficult to relieve (Arthur 1986).

## FORESTS

The forests of the world are likely to shift their distribution as a result of the warming trends predicted. Some questions exist as to the effect of warming on tropical forests because they are more sensitive to moisture than temperature, and there is some uncertainty about the effects of increasing greenhouse gas concentrations on precipitation (Shugart et al. 1986; Woodward 1989). In contrast, remarkable changes in the boreal forest, the major forest type in Alberta, are expected.

Each one degree Celsius rise in average temperature is expected to translate into a 100- to 150-kilometre, northward shift in the range of boreal forest (Roberts 1989).

Boreal forest communities are also likely to move up mountainsides. The changes in temperature up the slopes of mountains will roughly equate with temperature changes according to latitude. For example, differences in climate experienced over 250 kilometres in latitude will approximate those experienced over a 500-metre change in altitude. In some cases alpine communities may be displaced (Pain 1988).

Movement of the boreal forest, however, should not be equated with an increase in area, for this plant community will be simultaneously stressed at its northern and southern borders. For example, Sargent (1988) estimated that the area climatically suitable for boreal forest in Canada would advance by 70 million hectares on its northern edge and decrease by 170 million hectares on its southern edge.

Though the toll would be felt most at the southern limits of the forest, an obvious retreat would not be visible for at least a few decades. If the climate were to warm at a rate as fast as 0.8 degrees Celsius per decade, a rate that is higher than most computer models predict, forest dieback would start between the years 2000 and 2050 (Jager 1988). Gradual climate change would

result in reduced reproductive success of seedlings rather than death of mature trees. Seedlings will not replace mature trees as these older trees die or are harvested, and the southern border of the boreal forest will move northward.

Shifting of the northern limits of the boreal forest is likely to be slow. Trees have fairly long reproductive cycles, and disperse slowly. Studies of the changes in vegetation after the retreat of glaciers some 10,000 years ago indicate that spruce is best adapted to keeping pace with the habitat opportunities that will be made available as northern climates warm. But scientists are not sure that trees of the boreal forest are capable of keeping pace with climate warming. The ability of any tree species to expand northward depends on whether or not plants at the northern borders have the genetic potential to expand. Expansion also depends on the variety of habitats that become available. Since large portions of land northward of the current boreal forest is exposed bedrock, unsuitable soil is another impediment to migration of the boreal forest (Roberts 1988, 1989).

Human intervention may be required to compensate for lack of genetic plasticity and poor soil conditions. Site preparation and transplanting of trees may be necessary in order to enable the boreal forest to appreciably expand northward. This would be expensive, and would aggravate the economic inaccessibility of a northward-shifting boreal forest.

Consequently, though there may be up to 50 percent greater forest productivity in locations with sufficient water and nutrients (Wheaton and Singh 1988), aided by enhanced photosynthesis because of increased carbon dioxide concentrations (Green and Wright 1977), the total area of the boreal forest may decrease because of degradation of conditions at the southern boundary and slow migration at the northern boundary. Climate conditions may be right for the tree line to approach the Arctic Ocean (Zoltai 1988), but it is unlikely that boreal forests would expand to the extent permitted by climate.

Figure 8A and B illustrate the potential changes in the extent of the boreal forest in Alberta. They also show major northward and eastward shifts in the location of aspen parkland and grasslands. Aspen parkland would shift about 300 kilometres. Grassland ecosystems would move about 100 to 150 kilometres into territory previously occupied by parkland. Grassland expansion is anticipated because of higher temperatures and only slightly greater amounts of precipitation (Zoltai 1988; Wheaton and Singh 1988). Some westward movement of prairies into the mountains is also possible.

There is reason, however, to be concerned about more than just the effects of climate change on forest distribution. Associated disturbances would reduce forest productivity. Drier soil conditions that may accompany climate warming would increase the severity and frequency of forest fires. Severe weather, such as thunderstorms or tornadoes, would increase forest blowdown. Trees stressed by moisture deficiencies would probably be more susceptible to insect or disease damage (Fosberg 1989; Harrington 1989; Singh and Higginbotham 1988; Wheaton and Singh 1988). These developments would be unwelcome because forestry and other uses of forests make large contributions to the Alberta economy.

## AGRICULTURE

Grasslands and parkland ecosystems of Alberta, where most of the province's agriculture is concentrated, are likely to change due to the greenhouse effect. Noticeable changes in agriculture are therefore probable. With climate warming will come a significant increase in the length of the frost-free period, perhaps by as much as 20 to 30 percent, and a decrease in the maturation period for crops. Since the effects of climate warming would probably be relatively greater in northern parts of the province, northern crop choices are likely to change. For example, more wheat may be grown at the expense of canola (Stewart n.d.,

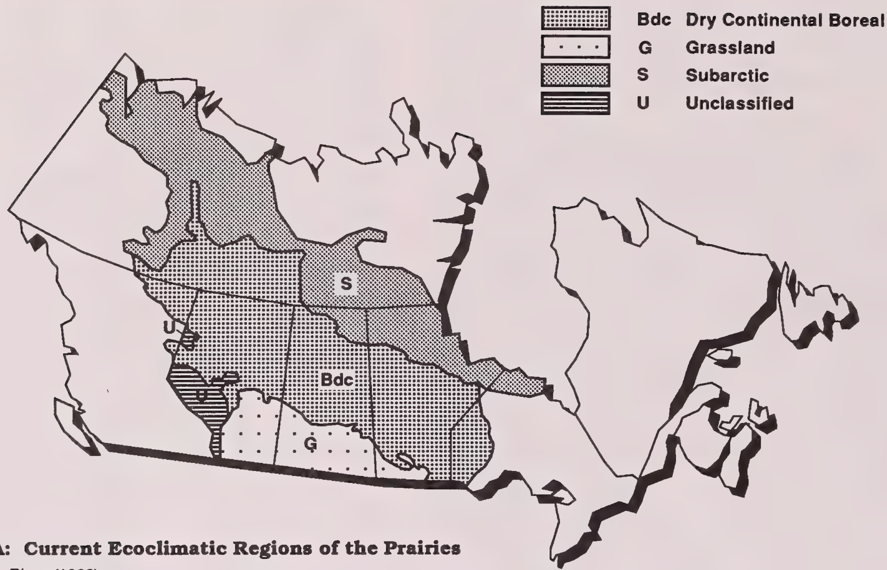



**Figure 8A: Current Ecoclimatic Regions of the Prairies**
Source: After Rizzo (1988)

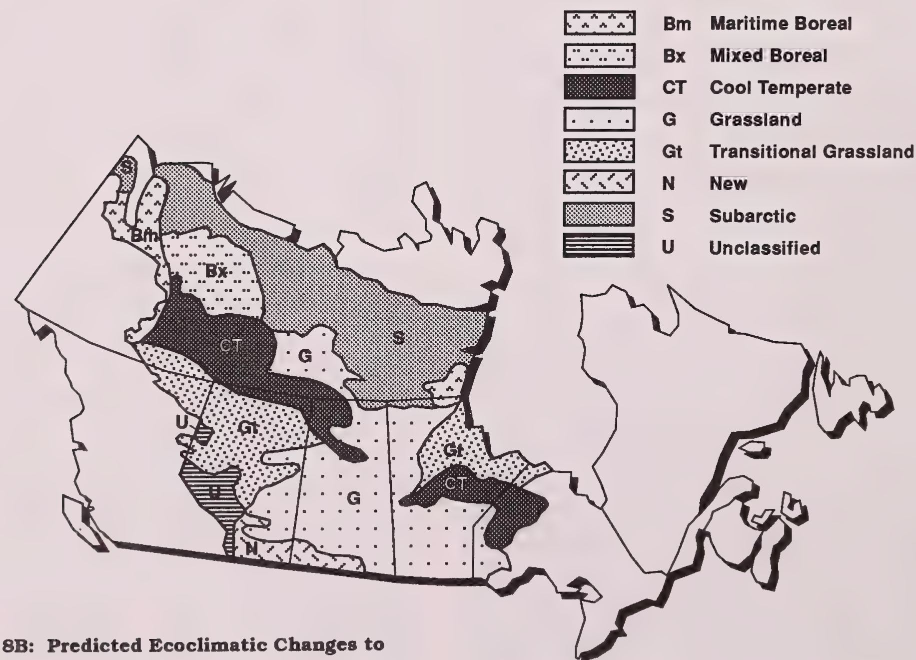



**Figure 8B: Predicted Ecoclimatic Changes to Prairie Regions Resulting from a Doubling of $CO_2$**
Source: After Rizzo (1988)

Parry and Carter 1989). Increased carbon dioxide concentrations may result in differential responses among plant species, as well as among plants that use carbon differently in photosynthesis. The plant composition of pastures could also change as a result of increased carbon dioxide concentrations. A decrease in production of desirable forage plants and an increase in less desirable ones is a possible consequence of climate change.

Alberta already experiences a water deficit for growing some crops. One result of increased carbon dioxide concentrations is that plants become more efficient in their use of water. This happens because the pores in leaves, the stomata, tend to close with higher carbon dioxide levels. Thus, the negative effect on plant productivity in water-short areas could be ameliorated. This compensation may be welcome because water deficits in southern Alberta would probably increase with climate warming (Lewis 1989). Model results used by the Alberta Research Council suggested decreases in summertime precipitation; yet, increases of 10 percent or more in precipitation are required to offset evaporation (Wong et al. 1989). As in Ontario, the risks to agricultural production in Alberta would be higher as a result of increased water deficits. The risks would be especially high in years with low precipitation (Cohen and Allsop 1988; Longley 1977).

Some simple arithmetic makes the large increases in risk of extreme events, given small changes in climate, very clear. If a drought rate changed from one-in-one hundred years to five-in-one hundred years the chances of two consecutive years of drought would increase by twenty-five times. These calculations assume that climate changes independently from year to year. A study done in North Dakota assessed the chances of crop yields at 24 or more percent lower than the median yields. Under the present climate in North Dakota, the chance of such low yields is 1 year in 8. A small change in climate (1 degree Celsius warmer and 10 percent drier) increased the risk to 1 in 2.3 years. This change represents more than a 300 percent increase in the risk of low yields (Warrick et al. 1986).

Water deficits in the dry southeast part of Alberta known as the Palliser Triangle could be worse than in the dry years of the 1930s. Agreements are already in place to allow 50 percent of the water in the South Saskatchewan River drainage basin to flow into Saskatchewan. If current increasing demands on Alberta's share of the water are coupled with decreased precipitation as a result of climate warming, greater irrigation efficiencies will be required in Alberta (Stewart n.d.).

Would the Palliser Triangle become desert-like? It is possible. Scientists think there are self-reinforcing relationships between rainfall patterns, vegetation cover, and soil temperature and nutrient properties. Climate warming or human use could result in a breakup of continuous grassland and degradation of semiarid grassland into scrub deserts (Schlesinger et al. 1990; Manabe and Wetherald 1986).

In areas that receive adequate rainfall, reduced plant transpiration could mean that plants use less water. Reduced use of water by plants might result in greater runoff. Soil erosion in northern Alberta could, therefore, develop into a more serious agricultural and environmental problem under the greenhouse effect than it is now.

Because more pests may thrive in a warmer climate or with increased concentrations of carbon dioxide, practicing agriculture might become more expensive. Various insects: locusts, aphids, and moths become more active as temperature or humidity rises. Farmers might also have to contend with two life cycles of insects in a growing season rather than one. When plants are fertilized with carbon dioxide the carbohydrate content increases and the protein content decreases. Consequently, more insects may eat more plants to obtain their protein requirements (Roberts 1988; Fajer et al. 1989). When considered in combination with serious crop dislocations, the extra costs

of farming due to pest problems could create added costs for farmers and consumers.

Ranchers as well as cereal farmers will be affected. Changes in the distribution, productivity, and species composition of forage lands, and the expanding geographical ranges of tropical parasites might cause problems (Pain 1988). Furthermore, increases in the number of very hot days and longer periods of warm weather could reduce conception rates, increase early embryo death, and decrease the production of livestock (McLean 1989). Because a larger portion of Alberta farm cash receipts result from livestock than crops (Alberta Treasury 1989a), the impact of climate warming on Alberta's farm and ranch economies could be consequential.

Computer modelling studies thus far do not consistently point to a negative or positive effect on Alberta's agricultural economy. However, the aggregated results of these models cloak the uneven distribution of the economic effects of climate change across the province (Arthur 1988; Goos 1989). Agriculture in southern Alberta is likely to be the hardest hit by the economic effects of climate change.

Moreover, linkages between agriculture and other sectors of the economy, for example, trade and service sectors, mean that the overall impact of climate change on the provincial economy would be larger than on agriculture alone. Studies on the effects of climate change on Saskatchewan agriculture showed that in terms of both dollars and jobs, the effects would be as large for the nonagricultural as for the agricultural parts of the economy (Stewart et al. 1988).

## BIOLOGICAL DIVERSITY

Worldwide decreases in biological diversity are expected to accompany climate warming. For example, in tropical and subtropical areas, two-thirds of the fish species live near coral reefs; these reefs would be threatened by rises in sea level more than by temperature increases. In arctic regions, sea ice is a vital component of the ecosystems. Algae growing on the underside of sea ice form the base of the food chain that supports large numbers of animals. The decrease in sea ice, primarily due to warmer winter temperatures, will exert a strong, probably negative, influence on the flora and fauna of northern ecosystems (Pain 1988).

There is worldwide concern about the loss of biological diversity in tropical areas, perhaps nowhere more so than in the Amazon River Basin. The diversity of this river basin may be a function of variations in climate and natural disturbances that have occurred even since the last glaciation. Conventional thinking, however, ascribes the diversity to climate stability. Models used to construct climate scenarios under enhanced carbon dioxide concentrations have predicted increases in rainfall in humid tropical areas (Jager 1988). The processes at work would be similar to those changes in climate that scientists recently believe to be responsible for the diversity there. However, the physical changes resulting from human activities, combined with changes induced by climate warming, may very well reduce biological diversity in the Amazon River Basin (Colinvaux 1989) and perhaps other tropical areas.

In some cases the causes of reduced biological diversity will be hard to discern. For animals like alligators and turtles, the ratio of newborn males to females depends on temperature. Climate change could threaten the survival of such animals by unbalancing the sex ratios. The survival of larger animals is also threatened by climate change. For example, large herds of female elephants often synchronize the time in which they are receptive to males. This maximizes the chances of fertilization by dominant bulls. Under low rainfall conditions herds may split up, which would allow access to the females by less dominant males. A reduction in genetic health of the elephant populations could result (Cubberly 1989; Pain 1988). The reduced conception rates or increased embryo deaths of larger animals, noted earlier in the discussion on agriculture, could result in the collapse of wild mammalian faunas at middle to high latitudes (McLean 1989).

Migratory birds, like many of those that pass through or nest in Alberta, depend upon rather precise timing for food and other resources. For example, shorebirds such as plovers and sanderlings migrate to South America, but stop at specific locations like Delaware Bay in the eastern United States to feed on the eggs of horseshoe crabs. These organisms provide shorebirds with enough food reserves to continue their flight, nonstop, to their wintering destinations. Should the timing of migration and food resources get out of phase as a result of climate change, the effects on migrant species could be disastrous (Myers et al. 1987). The ability of such species to adjust their routes and schedules is not known. However, in general, species that migrate or are capable of travelling great distances probably have a better chance of survival than endemic or sedentary ones (Cubberly 1989), because they are better able to search for new food resources and shelter.

Many parks and reserves have been established throughout the world to conserve plant and animal ecosystems or species. The reader may consult various discussion papers prepared for the Alberta Conservation Strategy project for more specific information about the conservation value of Alberta parks; see for example, Swinnerton (In press), Pachal (In press), and Webb (1987). Some of the sites in Alberta have been deemed worthy enough to be designated as World Heritage sites.

The species conservation efficiency of parks within Alberta is well recognized. One study found that the Four Mountain Parks system, of which Banff and Jasper national parks in Alberta are a part, is the only area of 15 examined in North America in which no animal species extinctions were recorded (Newmark 1987). The large area of the mountain parks and their consequent ability to support sufficiently large animal populations is thought to be the main reason for their conservation success. Other parts of the province are not as well protected as the mountain ecosystems.

In Alberta as elsewhere, climate change poses a threat to the conservation function of such parks. Several of these parks are surrounded by landscapes that have been radically altered; therefore, species that could otherwise keep pace with climate change will simply be unable to go elsewhere.

Without concomitant increases in habitat outside the parks, shifts in vegetation communities will reduce the habitat available to some species and endanger their survival. Steps to avoid the loss of biodiversity in parks and reserves include maintaining corridors between expanses of natural landscapes, keeping the areas adjacent to parks seminatural, and perhaps locating reserves near the northern edge of species ranges (Peters and Darling 1985).

The threat to species' survival stems from their potential inability to adapt to the rapid climate changes expected over the next hundred years or so. The geologic record may provide valuable insight into the rate and timing of large-scale extinctions.

Crowley and North (1988) determined that in the major cooling periods of the geologic past many extinctions occurred during the early stages of climate change. Thereafter the extinction events were smaller, even when the climate cooling was more severe than in the early stages. Presumably, this was because only hardy species lived beyond the initial climate shock. Most species are physiologically conservative, that is, their thermal tolerances evolve slowly (Cubberly 1989).

The biotic response of species is not always proportional to climate change, regardless of whether the change is gradual or abrupt. If climate warming results in species extinctions, a simple linear relationship between average temperature increases and species extinctions will not likely occur. The real danger lies in crossing a climate threshold that causes a watershed of species extinctions. The implications of reach-

ing a threshold must be taken seriously; there are already enough greenhouse gases in the atmosphere to cause climate changes.

## A RUNAWAY GREENHOUSE?

Most scenarios and discussions about climate warming assume that a doubling of carbon dioxide concentrations, or an equivalent, will occur. Twice present-day carbon dioxide concentrations is a convenient reference point. Though, lower levels (Harvey 1989) or higher levels are possible. A natural question follows: "How likely is a runaway greenhouse, one in which greenhouse gas concentrations rise many times more than at present and climate conditions on the earth become inhospitable?" (The planet venus is one place where this may have happened.)

Barring a 40 percent increase in sunlight reaching the earth and a saturated atmosphere free of clouds, the chances of earth becoming inhospitable are small. The long-term natural fluctuations of carbon dioxide in the atmosphere rival or exceed reasonable expectations about changes resulting from human activities. Earth's climate has fluctuated several times between temperature extremes both warmer and colder than present ones. Concentrations of carbon dioxide and methane have fluctuated roughly in tandem with temperature. Scientists are fairly sure that such things as weathering of sedimentary rocks, deposition of weathered materials on the ocean floor, and plate tectonics ultimately govern the amount of carbon dioxide in the atmosphere (Kasting et al. 1988; Houghton and Woodwell 1989; Berner and Lasaga 1989). The earth will, therefore, likely remain habitable, if not exactly hospitable for countless ages, except if there is devastation of the ozone layer.

That we are not likely to experience a runaway greenhouse takes little away from the significance of the problems that may lie ahead. But it does help us to avoid spending nervous energy on imaginary problems. Enough energy is required to solve real ones.

Chapter Six

# Climate Change Predictions: Chicken Talk?

The wisdom of fables can sometimes be used to guide our perceptions of and reactions to the world around us. One story that is particularly appropriate to discussions about the state of the atmosphere is *The Story of Chicken Little*. Recall that this is the story of the chicken that was knocked on the head by a falling acorn. The chicken's panic caused by thoughts that the sky was falling induced a state of unthinking hysteria in several other farm animals. In their confused state of mind the animals became easy prey for a fox.

A basic moral that can be taken from this story is for environmentally concerned citizens to maintain a sense of composure and rationality in the face of claims about the consequences of the greenhouse effect. Rationalizing must not be an excuse for inaction, but there is not enough evidence and understanding of climate change to panic over the prospect of the sky falling.

Chapter Six discusses some of the indicators for and against climate change, the problems associated with measuring climate change, and the challenges associated with using computer models to prepare climate scenarios. This material is presented to temper panic with rationality, in the hope that informed public or private actions in response to the greenhouse effect will be logical and appropriate.

## IS CLIMATE CHANGING?

So far, the evidence in support of recent climate warming due to the greenhouse effect is not substantial. For example, quicker warming at high latitudes, compared to low latitudes, has been predicted to occur under the greenhouse effect. Evidence that relatively large temperature increases at high latitudes are taking place includes increased depth to permafrost and thawing of peatlands in areas of discontinuous permafrost, increases in the average temperature of Canadian lakes, and declining extent of inland glaciers (Houghton and Woodwell 1989; Ovenden 1989).

There is some evidence of a decrease in the thickness of high arctic marine ice cover (Wadhams 1990; McLaren et al. 1990). And when Koerner and Fisher (1990) examined the melt layers in glacial ice core samples from the Canadian high arctic the samples indicated that the last 100 summers were the warmest of the past 1,000. These warmer temperatures may have caused the rises in global sea levels of 1 to 2.4 millimetres per year that have occurred since the beginning of this century (Peltier and Tushington 1989; Gornitz et al. 1982). This rise in sea levels is in line with predictions about the consequences of melting ice sheets and glaciers and thermal expansion of oceans. (With thermal expansion, sea levels rise because warm water has greater volume than cold water.)

Measurements of the temperature of the stratosphere also suggest climate changes may be at work. The ozone within the stratosphere normally absorbs UV radiation and consequently retains heat. Ozone destruction due to CFCs in the atmosphere should, therefore, result in a cooling of the stratosphere. Given a 50 percent reduction in stratospheric ozone, the stratosphere could cool by as much as 20 degrees Celsius. Also, increased concentrations of green-

house gases in the stratosphere would cause cooling due to the loss of infrared energy to space. Limited data sets have recorded small decreases in the temperature of the stratosphere (Ramananthan 1988; Cicerone 1990).

Temperatures at the earth's surface have been recorded for a much longer period. There has been a global average temperature increase since about 1850. Over the same interval the concentration of carbon dioxide has increased from about 280 parts per million by volume (ppmv) to 350 ppmv. Careful analysis of trends over the past 30 years point to a relationship between increases in carbon dioxide and temperature (Kuo et al. 1990). While the trends are roughly consistent with greenhouse gas theories, the axiom *correlation does not prove cause* justifies guardedness about attributing the rise in average temperature at the earth's surface to the greenhouse effect.

Questions exist about the adequacy of the surface temperature data base. Samples taken at sea and on land are too few to represent a global picture, and early data are unreliable sources of information (Ramananthan 1988).

Global sea surface temperatures seem especially problematic. For years the international merchant marine has collected sea surface temperatures, but the methodologies used may have biased temperature trends upward. Early measurements were made after hauling a bucket of ocean water aboard. The evaporation that is likely to have taken place during this process could have caused temperatures read by the thermometer to be cooler than actual sea temperature. Today, most sea surface temperatures are read from the ocean water pumped on board to cool the ship's engines, and this practice likely causes artificial warming of water samples. Comparison of temperature measurements taken by these two methods would magnify any real trend in sea surface warming (Monastersky 1989a; Jones and Wigley 1990).

Temperature records from land-based weather stations were also biased upward. Stations are typically located near urban centres, which are warmer than surrounding rural areas. Urban heat islands occur because cities contain more heat-absorbing asphalt, less cooling vegetation, and more heat-trapping pollution than rural areas. Most land and air surface temperature readings are still collected near urban centres, but corrections for urban heat islands have been made. Even after these corrections are considered, land temperature records show an estimated increase of about 0.4 degrees Celsius over the past century (Karl et al. 1988; Jones et al. 1989; Monastersky 1989a).

The estimate of the average increase of global surface temperatures is within the range of natural temperature fluctuation, so it is difficult to claim the increase is real. One is on even less solid footing to attribute the increase to greenhouse gases. If this warming is interpreted as a greenhouse signal, it is less than what might be expected given changes in carbon dioxide concentrations. Unequivocal evidence of an increase in average temperature should not be expected for another 10 to 20 years (Schneider 1989a; Monastersky 1989a; Kerr 1989b).

Inconsistencies in the pattern of temperature increase are also difficult to reconcile with the greenhouse effect. While carbon dioxide concentrations have shown a rather steady upward trend for the past century (certainly since 1958 when consistent measurements have been taken at the Mauna Loa Observatory in Hawaii), temperature increases have not been as regular.

Rises in temperature tend to be abrupt rather than smooth; that is, periods of rapid temperature increase are followed by periods of little or no movement (Ramananthan 1988). In fact, from the 1940s to the 1960s there was a slight cooling trend, followed by a sharp warming trend in the 1970s (Monastersky 1989a; Pearce 1989a; Jones and Wigley 1990).

Though rises in carbon dioxide levels and temperatures do not show similar patterns of increase, the disparity does not mean the greenhouse theory is invalidated. It may only mean that human understanding of greenhouse gases and climate effects is not very sophisticated, especially in the short term. For example, from the 1940s to

the 1960s, greenhouse warming may have been offset by natural or humanly induced climate variations.

Scientists examined the relationship between carbon dioxide, methane, and temperature, by analyzing air bubbles trapped in an ice core from the Antarctic. (The core represents ice deposited over 160 thousand years.) They found that carbon dioxide and methane rose and fell at the same time as, and proportionately with, temperature (Houghton and Woodwell 1989). This evidence suggests that the climate will warm over the longer term as the concentrations of greenhouse gases rise.

One remaining point needs to be made concerning rises in temperature. The 1980s have been characterized by high temperatures and drought in North America. The six warmest years over the past century occurred in the 1980s and this has been offered by some as evidence of the greenhouse effect. Alberta has also experienced warmer and drier conditions in the 1980s compared to average conditions. Warmer and drier conditions were most evident in winter months. The drought experienced in southern Alberta during the 1980s was worse than in the dirty thirties (Smit and Nkemdirim 1990; Wong et al. 1989).

Mathematical arguments against attributing these trends to greenhouse warming seem reasonable (Solow and Broadus 1989). Precise monitoring of global temperature changes from satellites from 1979 to 1988 did not show the obvious trends one might expect if the greenhouse gases were to blame for the climate of the 1980s (Spencer and Christy 1990). Changes in the circulation of the atmosphere resulting from natural variations in tropical Pacific Ocean circulation, the El Nino Southern Oscillation (ENSO), rather than the effects of greenhouse gases, appear to better explain the warm and droughty weather of the 1980s (Trenberth et al. 1988; Palmer and Brankovic 1989).

The causes of ocean oscillations are uncertain. Correlations between regular atmospheric oscillations and sunspot activity provide food for thought (Kerr 1988c), and interactions between greenhouse gases and the ENSOs are not well understood. Intense warming and evaporation due to heat trapping by greenhouse gases could possibly cause more intense changes in ocean circulation (Pearce 1989a).

Although the greenhouse effect may not have been the cause of climate anomalies of the past decade, the heat and drought we have experienced could be a sample of future climates should the greenhouse effect come to bear.

## CLIMATE MODELS

There is limited evidence to support theories of climate change. However, it would help the decision-making process if the scientific community had a better understanding of how climate components interact and could better model these interactions on computers. This scientific progress might make decision makers comfortable in giving more serious consideration to the prospect of climate warming.

Computer climate models are mathematical expressions of the various physical processes that influence climate. General Circulation Models (GCMs) are one group of popular, complex models. They predict changes over time of temperature, humidity, wind speed and direction, and soil moisture, among other variables. Rather than express the results as averages over the whole earth, GCMs break down the earth into grids of a few degrees latitude and longitude. GCMs also predict changes that occur with altitude (Schneider 1987; Dickinson 1986; Wong et al. 1989).

GCMs run on some of the most sophisticated computers in the world. The computer time necessary to estimate climate changes resulting from increases in greenhouse gases is in the order of months: testimony to the complexity of GCMs. Yet, despite the advanced nature of GCM technology, the usefulness of models to provide realistic scenarios of future climates within the very near future (when decisions must be made if the greenhouse effect is true) is limited.

There are two main reasons why undue stock cannot be placed on the results of climate models. One reason is that climate is not predictable by exactly the same physical laws that, for example, govern a billiard ball set in motion from the rails of a pool table. Climate systems have a strong element of randomness associated with them. There is a good chance that climate scenarios, even those derived from complex models run on powerful computers, will be in error in magnitude if not in direction. Another reason to treat GCM projections with caution is that climate responses may occur in sharp jumps over a short time rather than in a smooth, gradual fashion (Higuchi 1989; Ramananthan 1988). Abrupt changes in the reactions between ocean systems and the atmosphere could be responsible for cycles of glaciation, and for droughts in tropical areas. These changes underscore the possibility that climate might change quickly, and somewhat unpredictably, with increasing concentrations of greenhouse gases (Broecker and Denton 1990; Street-Perrott and Perrott 1990).

The second reason why computer projections should be approached with caution is fundamental to any model: the map is not the territory. Models are only abstractions of the real world around us. They only highlight the parts of larger systems that modellers think are significant; therefore, some aspects of reality are insufficiently portrayed. Attempts have been made to make the GCMs more realistic by building more components into them. However, insufficient knowledge, the lack of a unifying theory, which would help scientists to better understand climate systems and allow them to apply rigorous scientific tests (Ball 1989), and the lack of computing power, currently limit the utility of scenarios portrayed by General Circulation Models.

## The Role of Oceans

Oceans are major sinks for carbon dioxide. Long-term studies of atmospheric carbon dioxide at Muana Loa suggest that only 55 percent of carbon dioxide released from industrial activities remains in the atmosphere. Conventional thinking attributes absorption of most of the remaining 45 percent to oceans (Detwiler and Hall 1988). Tans et al. (1990), however, recently argued that oceans may not be that important.

The ability of oceans to take up carbon dioxide and slow its accumulation in the atmosphere is expected to decrease as oceans become warmer. Warm water absorbs less gas than cold water, and reduced sea ice formation, as a result of warmer oceans, decreases sea salinity. Warmer, less saline water is less dense and subsequently less able to sink to the ocean depths than cooler, heavier carbon dioxide-enriched water (National Environmental Research Council 1989).

Though the nature of the lags that occur between the time when oceans absorb heat, store it in their deeper layers, and release it again is not very well known, the radiative heat that oceans store in deep water can significantly delay warming of the atmosphere above them. Almost certainly the time lag is not fixed as has been assumed in the GCMs. The real time lag will depend on how a number of conditions combine to amplify or dampen gas-induced warming (Weisburd 1985).

Until recently one of the deficiencies of GCMs was that they assumed no transport of heat by oceans (Dickinson 1986). Nor did they allow for the possibility of changes in the general circulation of oceans and the atmosphere (Ramananthan 1988). Now GCM oceans can absorb heat and transfer it in surface waters toward the poles in currents that vary with climate change. Some models even generate elementary El Nino oscillations (Kerr 1989b).

The way that climate components *feedback*, or interact to reinforce or counteract each other, is important in assessing the near-term credibility of climate change predictions. The warming of oceans, for example, could enhance gas-induced atmospheric warming by releasing large amounts of the estimated 10,000 billion tonnes of methane, a greenhouse gas that is tied

up in underwater geological structures known as *clathrates* (Joyce 1988). This interaction between the atmosphere, oceans, and clathrates and their net effect — more methane in the atmosphere — is an example of *positive feedback*.

Warmer oceans could release carbon dioxide, and as a result, increase atmospheric temperatures. Kuo et al. (1990) studied the time intervals between increases in carbon dioxide levels and response of surface air temperatures. The study found that carbon dioxide levels lagged behind temperatures by about five months. This finding would be consistent with positive feedback between oceans and greenhouse warming.

More water vapor in the atmosphere may be another climatic consequence of warmed oceans. Warmer oceans will enhance evaporation of water into an atmosphere which, itself warmed by both the greenhouse effect and latent heat from water condensation, is increasingly able to absorb moisture. The amount of moisture in the atmosphere is important to climate warming because water vapor is a greenhouse gas and a prime controller of tropospheric temperatures. Recent evaluations of the effect of more water vapor from warmer oceans suggest that the potential for global warming may be much greater than previously thought (Raval and Ramananthan 1989; Gribben 1990).

## The Role of Clouds

Only recently have climatologists been able to get a first approximation of the overall effect of clouds on the earth's climate. Clouds appear to have a net cooling effect, notably at middle and high latitudes (Ramananthan et al. 1989). More clouds may result from the greater amounts of water vapor available to the atmosphere as a result of warmer oceans. Greenhouse warming may, therefore, be offset by cooling that occurs with cloudier conditions. Recently, there has been vigorous discussion about the ability of plant life, particularly plankton, to regulate and stabilize the earth's climate by releasing a chemical called *dimethyl sulphate*. This chemical forms condensation nuclei for clouds under warmer conditions (Charlson et al. 1987; Monastersky 1987; Kerr 1988b).

Because clouds strongly affect the earth's climate, small differences in the way that clouds are accounted for in GCMs will have a significant bearing on climate scenarios. Recent assessment of the effects of clouds is, however, from a very limited data base. Therefore, the role of clouds remains a very large source of uncertainty when GCMs are used to prepare scenarios of the greenhouse effect (Ramananthan 1988; Dickinson 1986; Monastersky 1989b).

## The Role of Biology

The carbon cycle of land-based ecosystems — a biological component of climate — is an important source of input for GCMs. Plants take up carbon dioxide from the atmosphere during photosynthesis. The extensive forests and grasslands of the world could be major sinks for the increasing amounts of carbon dioxide forced into the atmosphere, were it not for deforestation and the burning and ploughing of grasslands. Loss of vegetation, and subsequent unbalancing of the carbon cycle, is known to be severe in low latitude, tropical areas.

The destruction of tropical forests causes them to act more like carbon sources than sinks. Land use changes in tropical forests in 1980 released between 0.42 and 1.55 billion tonnes of carbon, mostly due to cleared vegetation (Detwiler and Hall 1988; Woodwell et al. 1983; Houghton 1990). Recent studies suggest that tropical grasslands may be as important as tropical forests in carbon cycling. Again, there is sizable variation in estimates of grassland productivity and carbon release with changes in land use (de Groot 1990). As wide ranging as these estimates of carbon release are, even less is known about the fertilization effects of greater ambient (atmospheric) concentrations of carbon dioxide on vegetation.

Whether vegetation will store carbon or release it will depend, over the short term, on rates of climate change and consequent ecosystem

status. If, for example, climate conditions in a forest quickly become unsuitable and there are no adjacent land areas with suitable climate and soil to which the forest can migrate, forest vegetation would decay and release its carbon without appreciable biologic uptake elsewhere.

If wetter conditions do not accompany warmer ones, peat could release large amounts of carbon dioxide and methane into the atmosphere. A rise in temperature of 4 degrees Celsius in organic soils could cause organic material to decompose and release 600 billion tonnes of carbon dioxide (Pearce 1988). What is likely under a warmer climate regime is that the rate of carbon dioxide release due to plant respiration and the breakdown of dead organic matter will exceed the rate of uptake due to photosynthesis and produce a positive feedback on climate change (Houghton and Woodwell 1989; Goreau 1990).

## Other Considerations

Projected levels of economic activity, demographics, energy demand, and consequent greenhouse gas production represent other significant uncertainties for climate models (Mintzer 1988; Keepin et al. 1986). The direction of change, however, is one that is likely to induce further climate warming.

More problems with GCMs could be identified. Doing so would do little to change the conclusion of the authors of this report that the inputs, components, and relationships portrayed within the various computer models are sophisticated guesswork that will produce results of limited use when decision makers look at corrective actions. We cannot say with absolute certainty that climate warming will occur. Yet, to do nothing for lack of conclusive evidence could be disastrous.

The greenhouse effect hypothesis is plausible. That no harm has yet come from human activities is hardly reassurance that none will come. If climate warming is taking place, are not the consequences too great to ignore? Shouldn't we buy some insurance against climate warming?

Chapter Seven

# Actions For Climate Change

Were grim prognoses for the earth's climate unequivocal, the choices to be made would be easier. Any action that is to be taken at this time, however, will be against a backdrop of uncertainty and debate (White 1990). Environmental scientists are often faced with a dilemma of insufficient proof when arguing for corrective actions (Crawford-Brown and Pearce 1989), but the gap between the gravity of the problem and the vacuum of solid information has probably never been as large as it is now.

When faced with difficult choices and insufficient information, people sometimes look to learning under different circumstances for insight. The following well-known ecological puzzle offers such an educational opportunity.

> *You own a pond on which a water lily is growing. The number of lilies doubles each day. If the lilies were allowed to grow unchecked, they would cover the pond in 30 days, choking off other forms of life in the water. You decide not to worry about cutting the plants back until they cover half the pond. When will that be?*

The answer is day 29. There is only one day in which to trim the plants. Were environmental threats to grow like the water lilies in the puzzle, large numbers and limits would be approached quickly (Meadows et al. 1972).

In describing this puzzle, the authors of this report are not suggesting that society is at day 29, or that climate changes will necessarily be sudden. However, mechanisms like enhanced release of methane, which could positively feedback on initial small increments of climate warming, and time lags between greenhouse gas release and effect, make unexpectedly large changes possible in a short period. It is human nature to discount the future. Waiting for conclusive evidence of climate change may only give us the satisfaction of being able to plot our own demise. For those who mark time, the signal marks the end.

Despite the uncertainties, climate change should be treated as a worldwide problem that must be addressed now. But agreement on the need to act hardly simplifies the problem of addressing climate warming. The kinds of changes to the atmosphere caused by human activities are complex, and no one action will stabilize a trend to climate change. For instance, reducing the emissions of CFCs to zero would still leave us the problem of carbon dioxide increases. Combinations of approaches are required.

## RESPONSES TO CLIMATE CHANGE

When considering ways to deal with climate change, three strategies are usually discussed: engineering countermeasures, adaptation, and mitigation.

### Engineering Countermeasures

One option for minimizing the effects of climate change would be to use *engineering countermeasures*, or technology, to purposefully intervene. To counteract climate warming, for example, technology could be used to spread dust in the stratosphere or to seed clouds. These countermeasures would increase reflection of sunlight incident on the earth's atmosphere. Another possible engineering countermeasure

would be to construct large satellite mirrors to reflect sunlight away from the earth (Seifritz 1989). Still another technical intervention would be to produce ozone artificially and pump it into the stratosphere in the hopes of raising ozone concentrations there (Monastersky 1989c). Or, iron might be spread onto biologically unproductive parts of the ocean to stimulate carbon dioxide uptake by plankton (Martin et al. 1990; Davies 1990; Anderson 1990). The well-recognized disadvantage of technological fixes (where in fact fixes are technologically possible) is that the resulting condition may be worse than the original problem. Costs may also be a significant obstacle to implementing engineering countermeasures.

Cures worse than the disease are most likely when our understanding of what happens after technological intervention is limited. Indeed, most of the discussion in Chapter Six argued that the climate experts still have much to learn about the greenhouse effect. Technological interventions like those above are, therefore, likely to have unintended consequences.

Legal instruments that deal with international tensions created by deliberate modifications of the climate are also underdeveloped. Technological interventions preclude dealing with causes. They often conceal deeper ecological and social processes and raise false hopes (Schneider 1989b; Glantz 1987). If the technological fixes fail, despair could freeze decision makers into inaction. Consequently, technological fixes should not be considered as long as other viable alternatives exist. They should only be used as a last-effort response to a severe and runaway change in the climate.

## Adaptation

The term *adaptive strategies* refers to planned activities that adjust components of the environment or changes the ways that human beings use the environment. Adaptive strategies are designed to reduce the consequences of a climate change (Jager 1988). Sometimes they are called *safe-fail* (rather than fail-safe) strategies. "The main point [of safe-fail adaptations] should be that if such a system fails, it will fail as kindly as possible, with a soft landing, and with manageable results" (Wiman 1990). Some adaptive strategies will be necessary if the greenhouse effect occurs. The kinds of adaptive strategies needed will depend on the severity of the climate change effects.

Timing, however, is critical. The longer decision makers wait to do something, the greater the required adaptation. The cost of adaptive changes and the time it takes to accomplish them should be given careful consideration. Something that takes 10 years to accomplish but is needed in 5 will not be very effective.

Coastlines, where sea levels could be expected to rise up to 1.5 metres with a rise in global temperatures of a few degrees Celsius, offer an example of environmental changes that would require expensive adaptation. Ecological and economic damage to coastal ecosystems like marshes, mangrove swamps, or coral reefs could occur. Furthermore, higher sea levels would mean increases in the "frequency and severity of flooding and damage to coastal structures, port facilities, and water management systems" (Jager 1988). The cost of adaptive responses to these events would be enormous. In the Netherlands alone, a one-metre rise in sea level would require minimum adjustments costing several billion dollars (US). Worldwide partial adaptations to rising sea levels, or temporary solutions would cost at least tens of billions of dollars (Jager 1988).

For interior dryland locations governments should evaluate legal, technical, and economic components of water management. Interbasin transfer of water to water-deficient areas (now inadvisable because of economic, legal, or political impediments) might be considered as a component of adaptive preparedness. Improved water use efficiency and management practices that increase the flexibility of water systems are other adaptive possibilities; these adaptations make sense regardless of anticipated climate changes because water is a limited, valuable resource.

Agricultural and other development plans prepared in accordance with the specific limitations of an area are a key element of adaptation. Planning for drought is appropriate for survival in semiarid areas where water shortages due to climate warming are likely to be most keenly felt. For example, development plans might be based on 9 inches of rainfall a year in places where the average rainfall is 12 inches. (In arid and semiarid regions the averages for annual rainfall are usually skewed because of small numbers of years with high rainfall.) Doing so would better prepare us for warmer, droughtier conditions under climate change (Hutchinson 1989; Glantz 1987; Agnew 1989). Global Climate Models, however, do not predict regional details reliably; this lack of reliability is a major stumbling block in attempts to use GCM results in planning adaptive strategies.

Survival with minimal hardship is possible, even under desert conditions, given a commitment to live within the means provided by the environment (Tobias 1988; Reader 1988). The question is whether or not consequent living conditions would match present-day expectations. However, scarcity of capital alone may cause society to make adjustments that are closer to the definition of the word *adaptation* than are interbasin water transfers and irrigation.

In anticipation of changed climate conditions, research should be conducted into the development of alternative crop strains. Agriculturalists would then have more options when faced with a wide range of plausible climate futures. Research into new crop varieties does not require large investments decades ahead of time, at least not to the same degree as some other adaptive strategies (Jager 1988). High returns from investments in agricultural research and recent refinements and innovations in biotechnology indicate that research into crop development might be of greater value than capital-intensive, adaptive projects such as dams and diversion structures. The environmental, economic, and social consequences of using newly developed *biotech* organisms must also be evaluated (Pimental et al. 1989).

## Mitigation

Mitigation strategies focus on reducing or stopping increases in concentrations of greenhouse gases in the atmosphere. Taking these pro-active steps will slow down climate change so that fewer climatic surprises will be encountered. It will also minimize the risk that rapid and drastic reduction in greenhouse gases will be needed in the future. Pro-active steps will also ensure that adaptation is easier to accomplish (Schneider 1989b; Miller and Mintzer 1986).

Very high priority must be given to reducing the injection of CFCs and halons into the atmosphere (White 1990; Flavin 1989). Mitigative efforts aimed at reducing greenhouse gas emissions will not be useful if there is too little ozone in the atmosphere to sustain the viability of organisms and ecosystems. Reduction of CFCs and halons would address the warming and ozone-destroying impact of these emissions.

Reports on the recent work of the Standing Committee on Environment of the House of Commons (1990) and on discussions at the 1988 Changing Atmosphere Conference in Toronto indicate recognition of the importance of reducing CFCs and halons.

For over a decade, use of CFCs as a propellant for most aerosols has been banned in North America. It should be banned wherever else it is still used. Unfortunately, on a global basis, aerosol cans still account for 33 percent of the production of CFC-11 and CFC-12, two of the most common and noxious formulations of CFCs (Shea 1988; Miller and Mintzer 1986). Compared to 10 years ago, aerosols now represent a smaller percentage of CFCs introduced into the atmosphere. Nonaerosol applications of CFCs, such as refrigerants, have been increasing steadily.

Research into the development of CFC substitutes holds promise. For example, hydrocarbons are now used as aerosol propellants instead

of CFCs. However, current product substitutes may entail an economic or performance loss and sometimes a health or safety risk. Assuming the quantities used are the same, there are, at present, some formulations of CFCs that are not as harmful to ozone in the stratosphere and do not contribute as much to greenhouse warming as CFC-11 and -12. These formulations, mostly hydrogenated fluorocarbons (HFCs) and hydrogenated chlorofluorocarbons (HCFCs), would not take long to bring into the market in commercial quantities (Miller and Mintzer 1986; Monastersky 1988a; Shea 1988; Doolittle 1989; Fisher et al. 1990a and 1990b; Prinn and Golembek 1990).

To use some of these substitutes, refrigeration equipment would have to be redesigned. For other cases, substitutes could be used with little or no change in equipment. The extra costs of using safer CFCs in new refrigerators may total in the millions, but add only a few dollars to the cost of each fridge. A tax on CFCs could be applied to ensure producers a high enough price to compensate their costs for developing and manufacturing substitutes. Better recovery and recycling, and higher efficiencies (for example, using reciprocating compressors on refrigerators that need only a third to a half of the refrigerants that rotary compressors do) are other worthwhile initiatives (Miller and Mintzer 1986; Olivier 1990).

Energy conservation as a broad policy direction is equally appropriate for reducing the introduction of other greenhouse gases into the atmosphere. Conservation through improved efficiency and substantial adoption of nonfossil fuel sources may be the only way for the industrial nations of the world to reduce carbon dioxide emissions over the next 50 years (Fulkerson et al. 1989; Goreau 1990; Houghton 1990).

A variety of policy instruments is available to encourage individuals and industry to conserve resources. One such option is the imposition of a carbon tax on fuels (see Chapter Thirteen). However, heightened environmental awareness and an interest in reducing day-to-day costs should minimize the need for government to adopt such coercive methods for promoting conservation.

Nuclear energy has been promoted as a means of reducing carbon dioxide emissions into the atmosphere. If breeder reactors are used, nuclear energy could be considered a renewable energy technology. Many people feel that, while it is produced without carbon dioxide emissions, nuclear energy is neither safe nor clean technology. Perhaps the most significant problem is safe disposal of used nuclear fuels. Renewable technology, energy efficiency, and conservation options make the promotion of nuclear options to prevent climate change questionable.

One direction that could benefit from more emphasis is development of renewable energy technology, such as geothermal, solar, hydrogen, and fusion technology. Many of the renewable energy initiatives have been blunted in recent years by continuing support of conventional energy sources and by reductions in government funding for research and development of renewables.

**Tie-in Value** — Mitigative strategies with *tie-in value* are promising because often they are feasible, effective, safe, and provide wide social and environmental benefits. They are common-sense actions that should be pursued (Schneider 1989b; Jarratt and Coates 1987) and given high priority. More costly measures could follow as scientific knowledge reduces uncertainties about climate change (White 1990).

One example of a strategy with high tie-in value is revegetation, particularly reforestation in tropical areas. Because trees store carbon, reforestation has been proposed as a partial and short-term solution to the greenhouse effect. Vast areas of land (roughly the size of Australia or the larger part of the lower 48 American states) would have to be reforested to reduce carbon dioxide concentrations in the atmosphere, and the area reforested would have to increase annually as carbon dioxide emissions increase. The prospect of reforestation is especially daunting in the developing world where deforestation is occurring

at a higher rate than ever before (Booth 1988; Postel and Heise 1988; Flavin 1989; Sedjo 1989; Houghton 1990; Goreau 1990).

However, some interesting initiatives exist. Australia is launching a national land care initiative, a major component of which is to plant a billion trees by the year 2000 (Climate Institute 1989). Similar efforts are taking place in the United States (Moulton and Andrasko 1990). One small American energy producer is committed to assisting with planting enough trees to offset the carbon dioxide that one of its new power plants will emit over the 40-year plant lifetime (Raloff 1988). Building reforestation costs into utility rates would mean that consumers would bear the full environmental and economic costs of fossil fuel generation. Such principles are germane to sustainable development (Bankes 1989).

Reforestation should always occur as a matter of normal business in forests that are managed sustainably for fibre; yet this has not occurred even in countries, like our own, that are dependent on forestry for their wealth. Alberta's record is very good in comparison to other provinces, but across Canada only about one acre out of every four harvested is reforested (Science Council of Canada 1983).

The tie-in benefits of reforestation are many. When planted on marginal lands, revegetation retards soil degradation and loss, and helps to conserve and purify runoff water. If managed for their inherent value as forests rather than solely for the production of fibre, reforested areas also offer recreational benefits, and aid in the achievement of biodiversity conservation goals. When planted in urban areas, trees reduce the demand for electricity to power air conditioners; they cast shade and cool the air as leaves transpire water. Further tie-in benefits would result at the end of the growing cycle if harvested wood were to displace fossil fuels.

Perhaps regional changes to the earth's albedo and modification of climate are the most significant tie-in values of reforestation. Well-vegetated areas have lower reflectivity than areas with less vegetation; they therefore enhance the amount of heat absorbed at the earth's surface. Much of the absorbed energy is used in evapotranspiration (transfer of moisture from soil and plants to the atmosphere), which generates clouds. Clouds so generated could reduce the amount of radiation that reaches the earth's surface and increase the amount of moisture available as rainfall (Bunyard 1985; Molion 1989).

Sharp differences in climate are detectable over short distances where land use and vegetative cover vary (Balling Jr. 1989; Friedman 1989; Molion 1989). Conceivably, on a local or regional scale, reforestation could dampen the effects of an overall increase in temperature caused by increases in the concentration of greenhouse gases. Reforested areas can evapotranspire water long after denuded areas dry out. This allows reforested areas to remain cooler in the daytime, on average, than denuded areas.

Like any initiative, reforestation has costs. For example, the Australian land care initiative will cost $320 million (Australian) (Climate Institute 1989). Were 465 million hectares of temperate forest required to sequester the estimated 2.9 billion tonnes of free carbon added to the atmosphere each year, reforestation could cost $372 billion (US) (Sedjo 1989).

Furthermore, reforestation would require social and demographic adjustments that are expensive, socially difficult, and time-consuming, perhaps more so in tropical, developing countries than in temperate developed ones (Jantzen 1988). Many developing countries are compelled to harvest their forest resources in an unsustainable manner to pay foreign debts. All nations will feel the environmental consequences of these activities. Developed countries might, therefore, consider forgiving staggering foreign debt as a means of making reforestation in developing countries more feasible. There are several approaches available to conserve tropical rain forests (Repetto 1990).

Overall, would the difficulties and costs of reforestation be any greater than those now incurred by do-nothing approaches, or by the

deforestation of tropical areas? Monies for reforestation would be well spent if the cost-benefit ratio of reforestation is anywhere near the United States estimates for reducing production and use of CFCs (Doolittle 1989). Notwithstanding favorable cost-benefit ratios of reforestation, the major strength of reforestation is technical feasibility.

Deforestation is only one way that developing countries are contributing to rising concentrations of greenhouse gases in the atmosphere. Their growing economies, expanding populations and per capita use of resources, and lack of capital for using the latest and most energy efficient technology suggest that most of the increase in future greenhouse gas emissions is likely to come from the Third World. By the year 2000, carbon dioxide emissions from the developing world may exceed levels of developed countries that belong to the Organization for Economic Co-operation and Development (OECD) (Fulkerson et al. 1989).

**Multilateral Cooperation** — A greater proportion of future economic growth in developing countries will be in primary or secondary industries. In developed countries, tertiary or service industries that are less energy consumptive than primary or secondary ones are expanding rapidly. To be of any environmental benefit, therefore, the actions industrialized nations take to reduce emissions will have to be complemented by encouraging similar reductions in the developing world. No one country has a majority effect on greenhouse warming; nor can any one country, acting alone, reduce climate warming by more than about 10 percent (Schneider 1989b).

The key to climate change mitigation is *multilateral cooperation* and development of a law of the atmosphere. A treaty linking the supply and demand of fossil fuels to the major sources and sinks of carbon makes sense. The prospects of reaching such agreements, before serious damage is done, are not good. The many obstacles to agreement on international environmental laws include fears developing countries have about the intentions of developed nations. Developing countries fear that their economic and social development will be restricted by developed countries who want to pass on the costs of their newfound concern for the environment. Developing countries are also concerned that being tied into multilateral agreements will not permit them to exercise sovereignty over their own affairs. Perhaps the greatest obstacle is a logistic one: coordinating a hierarchy of a large number of affected players and political jurisdictions to resolve environmental problems (Wood et al. 1989; Piddington 1989; Goreau 1990; Bankes 1989; Grubb 1989).

Given common recognition of the need to act, pollution quotas for each country will be difficult to settle. An arrangement that is fair to both developing and developed countries probably requires a greenhouse gas quota based on gross national product and population. The 1988 Changing Atmosphere Conference in Toronto recommended a reduction of approximately 20 percent of Canada's carbon dioxide emissions by 2005. The conference statement noted that reductions of 50 percent or more would be required to stabilize atmospheric carbon dioxide concentrations. Similar reductions are required for other greenhouse gases that have long residence times in the atmosphere.

While a Law of the Atmosphere is in the development stages, the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is an example of the kind of protocol required to curb climate change. The contributors of CFCs, who signed the Montreal Protocol, agreed to reduce their production and consumption of CFCs and halons to 1986 levels, with sequenced reductions to 50 percent of 1986 levels by 1999. Developing countries are allowed to delay their compliance with the guidelines defined by the Montreal Protocol.

The Montreal Protocol on ozone-depleting substances was reached with uncommon rapidity, most likely because ozone depletion in the stratosphere is an unequivocal health threat and CFCs are important greenhouse gases

(Bankes 1988 and 1989). The Montreal accord is very significant because of how it was reached, the precedent it sets for future initiatives to mitigate the greenhouse and other environmental threats, and for what it does. For example, its implementation will reduce the climate warming attributable to CFCs from the years 1986 to 2030 by three to seven times.

Even so, enforcement of restrictions far beyond those defined will be required to stabilize the atmospheric concentrations of the most environmentally unfriendly CFCs at levels near those of today (Koehler and Hajost 1990; Doolittle 1989; Wigley 1988). Furthermore, large, developing countries, for example, China and India, who are not signatories to the accord will have to abide within its limits. To achieve an agreement regarding other greenhouse gases that are not seen to pose the same health threat as CFCs will be very challenging.

The best policy directions to mitigate climate change will be ones that are both effective and acceptable. We place high value on agreement and consensus. Normally, this would mean a series of marginal, incremental policy adjustments, which may be ineffective if the climate warming hypothesis is true. Agreeing to reduce the emissions of greenhouse gases to achievable levels, rather than those needed to mute climate change, can be viewed with disdain, as practicing the art of the possible — politics. Public recognition of environmental issues in general, including the potentially serious consequences of climate change, may predispose nations to risk bolder measures.

What happens in Alberta will be a bellwether of responses to climate change, for Albertans would be among those Canadians hardest hit by the economic consequences of effective policies to limit greenhouse gas emissions. Alberta's special predicament and what its leaders are doing about climate change is described in following chapters.

Chapter Eight

# Reducing Fossil Fuel Use: Implications For Alberta

About ten percent of Canadians live in Alberta but this province is responsible for one-fifth to one-quarter of the country's emissions of nitrogen oxides and carbon dioxide. Albertans are the largest per capita emitters of carbon dioxide (Burn 1990) and nitrogen oxides (Federal/Provincial LRTAP Steering Committee 1989) in Canada. Alberta, therefore, will play an important role in reaching targets for emissions and reduction of fossil fuel use in any national strategy for climate warming.

Alberta's emissions, on both a total basis and a per capita basis, are high relative to the rest of Canada because 1) nearly all Alberta's electricity is produced by coal-fired thermal plants and 2) refined petroleum products, coal, and gas are produced to meet Alberta's needs as well as those of much of Canada and parts of the United States. In fact, more than two-thirds of the energy resources produced in Alberta end up outside the province.

## EMISSIONS INVENTORY

Inventory information shows that Alberta's total emissions of nitrogen oxides in 1985 were 447,233 tonnes, almost 25 percent of Canada's total of 2 million tonnes (Federal/Provincial LRTAP Steering Committee 1989). These emissions are due primarily to combustion of fossil fuels. Fifty percent (222,404 tonnes) are from stationary combustion sources and 44 percent (197,060 tonnes) from the transportation sector. Among the stationary sources, the largest emitters of nitrogen oxides were gas processing plants, which produced 131,480 tonnes. The second largest source was Alberta's coal-fired thermal power plants, which accounted for 67,810 tonnes of nitrogen oxide emissions (Table 2). Alberta Environment has also published inventories of emissions of nitrogen oxides (Alberta Environment 1988a) and of industrial sulphur dioxide emissions (Alberta Environment 1988b).

Alberta Energy identified Alberta's sources of carbon dioxide created during the production and use of fossil fuels (Table 3). These sources produced approximately 124.4 million tonnes (megatonnes (Mt)) of energy-related carbon dioxide per year in 1988. This is slightly more than 20 percent of the annual emissions in Canada. These emissions are forecast to increase to 176.8 million tonnes per year by 2005, an increase of 42 percent.

Alberta's energy industry produced about 51.7 million tonnes of carbon dioxide in 1988. Sixteen million tonnes of this was from the gas processing and reprocessing industry and 13 million tonnes from oil sands operations.

The residential sector contributed 14.7 million tonnes of carbon dioxide in 1988. Emission from houses made up 10.4 million tonnes or 71 percent of the residential total.

The commercial sector produced a total of 14.9 million tonnes of carbon dioxide in 1988. Commercial buildings, the largest subsector, contributed 8.7 million tonnes or 59 percent of the commercial sector total.

**Table 2: Nitrogen Oxide (NOx) Emissions in Alberta, 1985**

Total NOx Emissions: 447,233 Tonnes

| SECTOR | TONNES |
|---|---|
| **Industrial Processes** | |
| Kraft Pulping | 750 |
| Refineries | 2,664 |
| Other | 6,854 |
| Oil Sands | 15,975 |
| **Total Industrial** | **26,243** |
| **Fuel Combustion** | |
| Fuelwood | 67 |
| Power Plants (other than utility) | 246 |
| Refineries | 411 |
| Commercial | 4,534 |
| Residential | 6,920 |
| Other Industrial | 10,936 |
| Utility Power Plants | 67,810 |
| Gas Plants | 131,480 |
| **Total Combustion** | **222,404** |
| **Transportation** | |
| Marine | 16 |
| Aircraft | 4,753 |
| Off-road Gas | 10,083 |
| Railroads | 35,802 |
| On-road Gas | 63,746 |
| On-road Diesel | 82,660 |
| **Total Transportation** | **197,060** |
| **Incineration** | **471** |
| **Miscellaneous** | **1,055** |
| **TOTAL NOx EMISSIONS:** | **447,233** |

Source: Federal/Provincial LRTAP Steering Committee (1989)

**Table 3: Carbon Dioxide Emissions in Alberta, 1988**

Total $CO_2$ Emissions: 124.4 Megatonnes

| SECTOR | MEGATONNES (Mt) |
|---|---|
| **Industrial** | |
| Energy Industry | |
| Coal Mines | 0.43 |
| Nova Pipelines | 1.05 |
| Utility Pipelines | 1.24 |
| Gas Re-Processing Plants | 3.02 |
| Oil Refineries | 4.45 |
| Gas Flaring | 4.61 |
| Oil Fields | 4.98 |
| Raw $CO_2$ | 5.80 |
| Gas Processing | 12.94 |
| Oil Sands | 13.15 |
| Subtotal | 51.7 |
| Other | |
| Pulp and Paper | 0.33 |
| Cement Plants | .52 |
| Non-energy $CO_2$ | 1.32 |
| Manufacturing | 8.60 |
| Petrochemical | 9.44 |
| Subtotal | 20.2 |
| **Total Industrial** | **71.9** |
| **Total Commercial** | **14.9** |
| **Total Residential** | **14.7** |
| **Transportation** | |
| Rail | 0.86 |
| Farm Vehicles | 1.20 |
| Air | 1.83 |
| Commercial Vehicles | 7.86 |
| General Public Vehicles | 7.86 |
| **Total Transportation** | **19.6** |
| **Electric Transmission Losses** | 3.3 |
| **TOTAL $CO_2$ EMISSIONS:** | **124.4** |

Source: Burn (1990 )

The petrochemical industry and the manufacturing industry together made up 18 million tonnes of the 20.2 million tonnes of carbon dioxide emissions related to the other industry sector.

Several departments and agencies including Alberta Energy, Alberta Environment, Alberta Agriculture, Alberta Research Council, the Energy Resources Conservation Board (ERCB), and Alberta Oil Sands Technology and Research Authority (AOSTRA) are studying various aspects of air emissions. This work focuses on inventories of emissions and investigation of options to reduce them.

Alberta Environment is participating in developing a national management plan for emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) and has held meetings with industry and with the public to make them aware of implications for Alberta of federal and international emission reduction initiatives. Alberta Environment has also published "A Synthesis of Climatological Studies in Alberta from 1975 to 1986" (Papirnik et al. 1990), which compiles and summarizes the Alberta climate-related research from about 250 studies related to agriculture, forestry, and water resources.

Alberta Energy is beginning studies on "life cycle" emissions associated with the end uses of energy sources. Similar studies have also been recommended by Imperial Oil (1990). These studies might explore a variety of questions, for example: "What are the total emissions from the point at which coal is mined to the end use of electricity produced in coal-fired thermal plants?" "What emissions are produced when extracting bitumen from oil sands, converting it to synthetic crude oil and gasoline, and using that gasoline to power an automobile?" The data from such studies are important to understanding the consequences of policy decisions aimed at encouraging use of one fuel in preference to another.

## IMPLICATIONS

Many levels of government, both within Canada and around the world, are studying options to reduce emissions of carbon dioxide and other greenhouse gases.

Lower fossil fuel consumption is most often cited as the means for reducing carbon dioxide emissions. Some jurisdictions are already implementing emission reduction options. Their actions have implications for Alberta's fossil fuel industry because most of the market for Alberta's fossil fuels is beyond its borders (75 percent of Alberta's oil and gas production is sold outside the province). Reduction in demand for fossil fuels anywhere in these markets will decrease the demand for Alberta's products.

As shown in Figure 9, Alberta used only 22 percent of the oil it produced in 1988. The rest went to other parts of Canada (40 percent) and

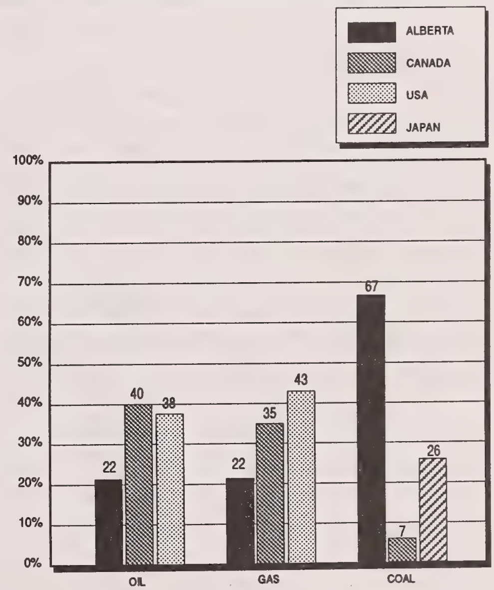



**Figure 9: Distribution of Alberta's Fossil Fuels**
Source: Data from ERCB (1988)

the United States (38 percent). Of the natural gas Alberta produced in 1988, Alberta, again, used only 22 percent. Thirty-five percent of Alberta's 1988 natural gas production went to other parts of Canada and 43 percent went to the United States. Alberta used 67 percent of the coal it produced, 7 percent went to other parts of Canada, and 26 percent went to Japan.

In any national control strategy, Alberta will be asked to make substantial reductions in emissions. In some areas, such as control of nitrogen oxide emissions, this may be difficult because Alberta already has high standards of emission control. In other areas, emissions from processing energy supplies for example, reductions may depend on actions outside Alberta that affect the demand for fossil fuels. The complex interrelations among different greenhouse gases, and their sources, require that proposed solutions to emission control problems and their implications be carefully considered.

In their report *The Greenhouse Effect and the Alberta Fossil Fuel Industry*, the Alberta Oil Sands Technology and Research Authority (AOSTRA) states that demand for natural gas will probably increase. This demand for natural gas will increase as gas replaces higher-carbon fuels and is used as a source of hydrogen for upgrading these fuels. Reduced consumption of the higher-carbon fuels would result in smaller domestic and export markets for coal. Demand for oil would also decrease with increased conservation and replacement by other fuels. The development of renewable energy sources and nonfuel markets for hydrocarbons could serve as supplemental forms of economic activity for Alberta (Wiggins and Yurko 1989).

The Toronto Conference used 1988 as the baseline year against which to calculate reductions in carbon dioxide emissions. In 1988, conventional crude oil production in Alberta totalled 57.5 million cubic metres and bitumen and synthetic crude oil production added another 19 million cubic metres (ERCB 1988). Natural gas sales totalled 77 billion cubic metres. Sales of Alberta coal in 1988 amounted to 29 million tonnes. This production of fossil fuels was worth more than $14 billion to Alberta's economy. Natural gas contributed $4.4 billion, crude petroleum contributed $7.7 billion, and coal contributed $456 million — the bulk of the value that fossil fuel production contributed to Alberta's economy (Alberta Treasury 1989b).

If Alberta were to meet the target suggested by the Toronto Conference, emissions of carbon dioxide would have to be reduced from the 124.4 megatonnes emitted in 1988 to about 100 megatonnes. Using current energy requirement forecasts, carbon dioxide emissions in Alberta are projected to increase to 176.8 megatonnes by 2005. Achieving carbon dioxide emission levels of 100 megatonnes by 2005 would mean that energy demand would have to decrease 43 percent below projected demand levels.

If a mere 20 percent reduction in production from 1988 levels occurred for all fossil fuels then production of conventional oil would fall to below the sales levels last experienced in 1982, the low point in oil markets in the 1980s. Natural gas production would be slightly above 1983 sales levels, the lowest volume sold in the 1980s. And a 20 percent decrease in coal production would bring sales down to 1984 levels.

The early 1980s in Alberta were post-boom years. When describing these years, the Department of Energy and Natural Resources Annual Report for the year ending March 31, 1983 states, "Activity in the oil and gas industry of Alberta declined further from the depressed level of 1981, the result of a lingering worldwide recession, uncertain markets and the continuing effects of the National Energy Program" (Alberta Energy and Natural Resources 1983). The Energy Resources Conservation Board report for the same year states: "As a direct result of the decline in new investment in the Alberta energy industry, employment also was down during the year. Especially hard hit was the oil and gas service industry" (ERCB 1983).

These comments were stimulated by a drop in natural gas production of about 6 percent by

volume between 1979 and 1980, followed by a further drop of 1.5 percent in 1981 and an increase of almost 3 percent in 1982. Oil production declined about 4.5 percent from 1979 to 1980, more than 9 percent from 1980 to 1981, and more than 2 percent from 1981 to 1982 before beginning a recovery. Coal production increased in all years (Alberta Treasury 1984). Despite the decreases in production for gas and oil, the value of production increased because prices increased. Nevertheless, Alberta's economy was severely affected; production cuts reduced employment in the oil and gas industry and related service companies.

A 20 percent reduction in fossil fuel production over 15 years would not be possible without a substantial shift in employment, investment, and revenue patterns for Alberta and for Canada. Reduction in fossil fuel use does not necessarily mean a decrease in overall industrial activity. Much of the reduction could be achieved using technology that is available and economically efficient. However, substantial government efforts in the form of incentives, disincentives, regulation, and education would be needed to stimulate the desired change.

The task of affecting the fundamental socioeconomic values and, subsequently, the lifestyle choices of millions of individuals will be a major challenge for Alberta's leaders. The result — improved efficiency and reduced energy consumption — could lower total energy costs and put more disposable income in the hands of consumers. Investment capital that is shifted from fossil fuel projects would be available for investment in other energy technology and conservation-related industries or economic diversification.

Renewable energy developments will probably offset some fossil fuel uses. Renewable energy developments tend to be smaller, more labor intensive, and more flexible to local and regional needs and demands. These developments could, therefore, offer opportunities for regional economic development and employment. Many renewable energy projects may make economic sense especially when considered as part of an energy-related emissions reduction strategy. Renewable energy sources need to be assessed in light of predicted climate changes and the long-term viability of capital intensive projects.

Fossil fuel developments could also become more responsive to changes in demand. For example, large-scale developments, which take years to plan and construct, might be discouraged in favor of developments that are smaller and more timely with respect to matching supply with demand.

Flexible supply will become more important if demand for energy decreases. Smaller facilities and incremental expansion are more attractive economically if demand is increasing slowly. Slower growth in energy demand will also allow developers more time for planning and more time for technological development and modification.

The greatest immediate changes in the demand for energy are likely to occur in the transportation sector. For example, vehicle efficiencies will likely improve. The planned reduction of gasoline-powered cars in Los Angeles could increase the use of alternative fuel vehicles in that city. This in turn could make these cars more widely available throughout North America.

A growing market for alternative vehicle fuels would encourage the development of methanol (initially from natural gas and eventually from wood) and ethanol fuels. Blessed with large supplies of natural gas, Alberta should assess the long-term market for natural gas powered vehicles and establish expertise in that area. Technology suitable for farm vehicles would benefit Albertans and provide exportable technology.

Urban and interurban transportation programs will probably play an important part in reducing transportation fuel use. Government programs might encourage efficient public transportation systems and improvements in freight movement between major municipalities. This might require a rethinking of urban planning

that is predicated on continued use of the automobile.

Stationary motors and compressors are an important source of emissions of nitrogen oxides and carbon dioxide. Alberta's industry, especially the oil and gas sector, has developed the expertise and technology to reduce these emissions. This technology would be a valuable export commodity.

Because electricity generation in Alberta is predominantly fueled by coal, emphasis must be placed on using only the best available clean coal technology. Low nitrogen oxide, sulphur oxide (LNS) burners could be retrofitted to existing plants but there is little incentive. This type of upgrade is not required by emission standards; therefore, it is not allowable as an expense that can be recouped through rate increases. Regulating the reduction of nitrogen oxide and sulphur dioxide emissions from power plants may be necessary to get this beneficial technology in place.

Another technology, coal gasification, converts coal into gas to power a turbine. The heat from the turbine exhaust is also used to produce electricity. These plants have low emissions of nitrogen oxide and sulphur oxide. These plants also offer improved energy efficiency. As a result, the carbon dioxide emissions of these plants could be reduced by up to 15 percent. By using the large amounts of remaining waste heat in applications such as district heating, the overall efficiency for coal use in power generation could theoretically rise to 70 to 80 percent.

Coal is an abundant and inexpensive energy source in many countries. It is the likely fuel to meet growing energy demands in China and India. In consideration of the global nature of climate warming, it is important that coal be used as efficiently and as cleanly as possible whether in Canada or abroad. The use of coal as a fuel will not disappear overnight and the development of clean coal technology provides many opportunities for domestic and export markets. Alberta's developing technology could play a role in the global marketplace.

The AOSTRA report (Wiggins and Yurko 1989) suggests that methods be developed for reducing carbon dioxide emissions from fossil fuels to permit their continued use. One method is to upgrade fuels by increasing the hydrogen to carbon ratio. This would reduce carbon dioxide emissions for a given energy output. Because this upgrading process requires hydrogen, Alberta Energy is coordinating a research program aimed at developing sufficient, cost-effective, energy-efficient supplies of hydrogen to meet the projected demand. Currently, most hydrogen is manufactured from natural gas. The emissions associated with the production of hydrogen need to be considered in this research to properly evaluate the net change in atmospheric emissions.

Reduction of carbon dioxide emissions from sources other than fossil fuels, such as in the manufacture of nitrogen fertilizers, lime, and portland cement, also needs to be investigated (Wiggins and Yurko 1989).

Chapter Nine

# Reducing Greenhouse Gases

Climate change will have a direct, major impact on Alberta's economy because it will alter the conditions of renewable resource industries such as forestry, agriculture, and recreation. Likewise, any emissions control agreement that regulates the use of fossil fuels will also have a major impact on the economic well-being of this province.

Alberta should, therefore, act now to determine how it can respond to changing social attitudes toward the environment and take advantage of the opportunities that may arise as a result of climate change strategies.

## GOVERNMENT INITIATIVES

Canada is supporting international efforts and positioning itself as a leader in environmental issues. For example, Canada hosted the meeting in Montreal that led to the signing of the Protocol on Substances that Deplete the Ozone Layer. Canada also signed an international convention with several European countries to reduce sulphur emissions by at least 30 percent by 1993, and is working on an agreement with the United States to further reduce emissions of sulphur compounds. The United Nations Economic Commission for Europe protocol (on nitrogen oxide emissions control), which Canada signed, requires that nitrogen oxide emissions in this country be frozen at the 1987 level by 1994. Further actions will be negotiated with the United States.

In Toronto, 1988, the Government of Canada hosted the international conference "The Changing Atmosphere: Implications for Global Security." Since that time, Canada has been examining ways to reduce emissions of carbon dioxide and the implications of such reductions. These efforts may eventually become part of an international agreement to limit emissions. The efforts of Canada, acting alone, will have a negligible effect on global emissions. If carbon dioxide and other greenhouse gases are to be reduced globally then global action is required.

To meet Canada's international commitments, federal and provincial governments must develop coordinated strategies. Transport Canada and Environment Canada are investigating strategies to reduce nitrogen oxide emissions from mobile sources. The Federal/Provincial Long-Range Transport of Air Pollutants (LRTAP) Steering Committee (1990) has developed a draft management plan for reducing emissions of nitrogen oxides and volatile organic compounds (VOCs). This draft is being discussed with the various stakeholders. A final plan is to be presented to the Canadian Council of Ministers of the Environment (CCME) in October 1990.

In March 1990, the Canadian Council of Ministers of the Environment instructed a steering committee of energy deputy ministers to develop a comprehensive National Action Strategy for Climate Warming. The steering committee is to work in cooperation with a committee of energy deputy ministers and report to CCME in November 1990.

National-level research activities on climate change are coordinated through the Canadian Climate Centre of Environment Canada in Downsview, Ontario. This centre has funded studies of the potential impacts of climate warming on various sectors of Canada's economy.

A major study is being done by the federal, provincial, and territorial energy ministers. The Task Force on Energy and the Environment, established by these energy ministers, is studying options and implications of reducing carbon dioxide emissions by 20 percent of 1988 levels by 2005. This target was recommended at the 1988 Toronto Conference on The Changing Atmosphere (Environment Canada 1988). The task force is considering the implications, costs and benefits, and consequences of achieving this 20 percent reduction.

Other federal government departments are studying specific aspects of climate change. For example, the Federal Department of Forestry is doing a long-term study of the role of forests in the earth's carbon dioxide balance. As well, they are studying the role of peatlands in the storage or release of carbon dioxide. The results will be important because large areas of peatlands are now permanently frozen. If this permafrost melts under a warmer climate, enhanced biological activity could affect the overall release of carbon dioxide and methane.

The Alberta government is part of the CCME and the Task Force on Energy and the Environment. In addition to these efforts, Alberta is undertaking a program to develop its own Clean Air Strategy. This program will include all energy-related emissions and examine the greenhouse effect, acid depositions (acid rain), and smog. The program, which is coordinated by Alberta Energy and Alberta Environment, will define problem areas, identify options, and develop recommendations and possible strategies.

The complex interrelations among different greenhouse gases and their sources require that proposed solutions to emission control problems and their implications be carefully considered. Chapters Ten through Thirteen describe actions that could address climate warming. These actions can be broadly grouped as mitigative strategies or adaptive strategies.

Currently, the greatest amount of government effort is focused on preparing mitigative strategies. It is less expensive and easier to deal with causes of problems (anticipate and prevent) than to correct problems after they happen (react and cure). The best mitigative actions are activities that reduce greenhouse gas emissions and provide other tie-in benefits. Energy conservation and improvements in energy-use efficiency, for example, will reduce emissions and conserve energy resources for future generations. Actions with tie-in value are the obvious first choice when responding to climate change. Such strategies, however, will not be enough to stabilize the atmospheric concentrations of greenhouse gases.

In this paper, *mitigative strategies* refers specifically to those actions that reduce or mitigate the rate and amount of climate change, giving the scientific community and decision makers more time to understand the changes and develop the best corrective or adaptive actions. Mitigation recognizes the likelihood that it will only be possible to reduce or mitigate impacts rather than prevent climate change.

As the City of Vancouver's Task Force on Atmospheric Change (1990) put it: "The problem is one of choosing between a politically easy course that exposes society to potential hazard at an unknown level of risk, and a politically difficult course that may reduce the long-term hazard but imposes significant short-term costs on society. If the crisis is real and our decision makers don't act, society is condemned to suffer the consequences. However, if decision makers do act decisively and effectively, we may never know how great the hazard was." This statement accurately expresses the nature of the problem that faces Albertans.

The complex nature of climate warming offers both opportunities and challenges. There is an almost unlimited scope to actions that will help reduce climate warming. Before implementing any strategies, decision makers should consider the interactions among the various greenhouse gases and make sure that actions to control one gas do not unintentionally increase the impact of other gases.

Chapter Ten

# Mitigative Strategies: Reducing Carbon Dioxide Emissions

## OVERVIEW

The initial report of the Federal/Provincial/Territorial Task Force on Energy and the Environment (1989) noted that global warming is an international issue and that actions in Canada must be linked to developments around the world. At that time, the task force did not believe that Canada should act alone and take actions that could alter its economy and harm its international competitiveness.

In 1990, the task force reconfirmed its position that "A solution will require cooperative action, and will have to take into account the different social, financial, economic, and environmental realities which each country faces" (Federal/Provincial/Territorial Task Force on Energy and the Environment 1990).

The task force did, however, state that there are opportunities for Canada to demonstrate leadership. For example, the task force suggested Canada take those actions that lessen greenhouse gas emissions and are also economically attractive for Canadian society.

To accomplish the overall goal of reducing emissions, the task force had recommended each province and territory

- develop detailed inventories of carbon dioxide emissions and study abatement technology appropriate for their jurisdiction;
- analyze the potential regional impacts of global warming;
- examine the most cost-effective measures for reducing greenhouse gas emissions;
- consult with representatives of affected industry, environmental groups, consumer groups, scientists and social scientists, and interested individuals (Federal/Provincial/Territorial Task Force on Energy and the Environment 1989).

Preliminary results of the regional analysis were presented at the Conference of Energy Ministers in April 1990. Regional analysis showed that the main sources of carbon dioxide emissions vary considerably across Canada. Therefore, measures to reduce emissions will vary regionally.

With respect to achieving a 20 percent reduction target, the task force report (1989) initially stated that it is "prudent to continue to regard the recommendation of the Toronto conference as an illustrative target rather than as a formally adopted goal" (Federal/Provincial/Territorial Task Force on Energy and the Environment 1989).

This view was reconfirmed in 1990 when the task force found that there was agreement among the provinces and territories that reducing emissions 20 percent by 2005 "is not practical at this time." Achievement of a 20 percent reduction "could cause significant economic dislocation and would require significant changes in lifestyle." There was general agreement, however, that the provinces and territories should work toward stabilizing and eventually reducing carbon

dioxide emission levels (Federal/Provincial/Territorial Task Force on Energy and the Environment 1990).

Alberta's report to the 1990 Energy Ministers' Conference was a preliminary review of the potential for energy conservation and fuel substitution measures to reduce energy demand and carbon dioxide emissions. The Alberta report identified a potential list of conservation measures. A measure's implementation cost has to be recovered through energy cost savings in 10 years or less to qualify for inclusion.

A separate report puts a figure of 7 percent on the potential for reduction of carbon dioxide emissions below 1988 levels by 2005 (Alberta Energy 1990). This is an ultimate figure. It assumes, among other things, that all possible measures are adopted by all sources and that implementation occurs immediately. When considered in light of the projected 42 percent increase in emissions by 2005, which is based on current projections of energy requirements, a real reduction of 7 percent would be a substantial accomplishment. (An updated version of this report will be available by the end of 1990.)

The greatest potential for energy end-use reductions lies in the industrial sector (particularly the energy production industry) and in the transportation sector. Industry cogeneration potential (to produce both electricity and useful hot water) appears significant (Webb 1983), but further study is required to determine how rapidly this technology might be adopted. Retrofit energy reductions constitute the major portion of the energy savings potential.

An Energy, Mines, and Resources Canada report (1990) describes a number of energy-efficiency and alternate-energy initiatives. It is estimated in the report that pursuing these initiatives could reduce carbon dioxide emissions in Canada by 35 to 50 megatonnes between the years 1990 and 2000. This is about half the amount needed to stabilize Canada's emissions at the 1990 level.

## CARBON DIOXIDE

Carbon dioxide is the most significant contributor to global warming. It is, therefore, the focus of mitigation strategies being developed. These strategies can be grouped into three categories: those that remove carbon dioxide after it has been produced (removal options), those that reduce carbon dioxide emissions by changing fuel sources or processes (avoidance options), and those that reduce consumption of energy (energy conservation and efficiency options).

### Removal Options

*Removal options* refers to technology that, directly or indirectly, removes substances from the emission stream and disposes of them in some manner. Some options do not remove carbon dioxide directly. Instead, they offset emissions by increasing carbon storage in one part of the carbon cycle. Increased reforestation is one such offset practice. Reforested trees store carbon, offsetting emissions from burning fossil fuels.

**Disposal** — Carbon dioxide can be removed from the flue gas produced in furnaces. Its concentration in flue gas ranges from 8 percent by volume for natural gas-fired furnaces to 14 percent for coal-fired furnaces. In coal gasification plants, much higher concentrations of carbon dioxide are produced in the flue gas, making carbon dioxide extraction more cost effective.

The recovered carbon dioxide can be injected into salt caverns or depleted oil and gas reservoirs or used to enhance oil recovery. Long-term storage in salt caverns or depleted reservoirs is technically feasible, safe, and effective. The principal impediments to disposing of carbon dioxide in this manner are the procedure's high capital costs and energy consumption (Wiggins and Yurko 1989).

In 1982, flue gas stripping as a source of carbon dioxide for enhanced oil recovery was found to be economically feasible if the price of oil

was around $30 per barrel. But, due to declining oil prices, the project was cancelled. Increased oil prices would result in re-evaluation of similar projects.

Enhanced oil recovery projects represent a limited market for carbon dioxide, although TransAlta Utilities (Corporation) Ltd. estimates that enhanced oil recovery could take the carbon dioxide output from Alberta's power plants for 20 years (Standing Committee on Environment (Dec. 14) 1989c). Once an oil field has been pressurized, additional injections of carbon dioxide are needed only to maintain pressure as oil is extracted.

**Reforestation** — A strategy to remove carbon from the global carbon cycle can have short-term and permanent components. Increased reforestation is a feasible, short-term component. The Government of Alberta, in cooperation with federal government forestry and agriculture departments, could encourage reforestation of marginal agricultural lands. This program would complement current programs aimed at removing marginal land from agricultural production for water and wind erosion protection and sustainable agriculture initiatives.

Any reforestation program would need to consider the uncertainty of future climate and forest growing conditions. Reforestation, especially along the southern edges of the present forest, may not yield commercially viable forests. However, as long as forests are actively accumulating carbon, they deliver a net benefit to carbon reduction. Wildlife and forest-based activities, in general, would benefit from an increase in forested area. As well, Alberta could continue its practice of delaying or limiting the sale of marginal land currently occupied by forests. This would help reduce deforestation in the province.

Reforestation is not a permanent solution to offsetting carbon emissions nor can some countries or regions increase forested areas sufficiently to offset the projected increases in carbon emissions.

## Avoidance Options

*Avoidance options* reduce demand for the energy source that creates the emissions. These actions generally include a reduction in fossil fuel use or a shift to a less carbon-intensive fuel. Avoidance options do not necessarily result in an overall reduction in energy use.

**Renewable Energy Sources** — Alberta has a variety of renewable energy sources available: biomass, solar radiation, wind power, hydro power, and geothermal energy (Energy and Non-Renewable Resources Sub-Committee 1988). These energy sources could supplement fossil fuels. In 1986, six Alberta wind energy producers were connected with TransAlta Utilities and sold 48 megawatt hours of power to the utility (*Sol* 1987).

The Alberta Small Power Research and Development Act encourages independent production of electricity from small facilities by guaranteeing a contract price for purchase by Alberta's utilities. And under the Southwest Alberta Renewable Energy Initiative, the Alberta government is providing $3 million over three years to assist the private sector in the demonstration of wind, solar, and other renewable energy technology.

Forest biomass can be managed as a renewable energy source reducing the need for fossil fuels. Alberta's forest industry already uses wood wastes to provide heat, steam, and electricity for its processing operations. Although proposals have been put forward, there are no projects using biomass to produce and market steam or electricity.

Wood fibre could also be used to produce methanol or ethanol as fuels to replace gasoline. Standard cars can run on 10 percent ethanol or methanol blends without modification. Grain ethanol is currently used in 7 percent of all gasoline in the United States. Most methanol now comes from the reforming of natural gas.

Technology to convert wood to ethanol is being developed at a pilot plant near Ottawa. Statements made by Mr. B. Foody, President of the Iogen Corporation, to the House of Commons Standing Committee on Environment indicate that the cost of producing ethanol from wood could be about 21 cents per litre by 1995, making it cost-competitive with gasoline (Standing Committee on Environment (Dec. 12) 1989b). Mr. Foody estimated that conversion of only 8 percent of Canada's farmland to forest plantations destined for ethanol plants would be enough to replace all Canada's gasoline needs. The reforestation effort could be funded with a gasoline tax of between 0.5 cents and 1 cent per litre.

The use of ethanol or methanol offers benefits in the reduction of volatile organic compounds, nitrogen oxides, and carbon monoxide emissions. These benefits are a motivating force behind development of alternative vehicle fuels especially in the United States, even though concerns remain about ethanol and methanol combustion products such as formaldehyde. It should be noted that if reduction in volatile organic compounds is the primary objective, then reducing the volatility (ease of evaporation) of gasoline would be more cost effective (Walls and Krupnik 1990).

Distribution systems and consumer purchasing patterns are current barriers to achieving a rapid shift toward use of renewable energy sources. Ethanol is, for example, unlikely to make major inroads into the transportation market unless its use is supported by government policies and programs.

Any increase in ethanol or other renewable energy fuels would mean a reduction in demand for refined petroleum products. The increased use of alternative fuels would also be in competition with programs encouraging use of propane, compressed natural gas, and methanol from natural gas. Ethanol fuels, however, may be a better long-term alternative if energy use trends shift to renewable energy sources.

**Fuel Switching —** Some fuels release more carbon dioxide per unit of energy output than others because of their different carbon to hydrogen ratios. Wiggins and Yurko (1989) give the following carbon dioxide emissions in tonnes per terajoule (TJ):

| Fuel | Tonnes of $CO_2$ Emitted per TJ |
|---|---|
| Natural Gas | 50 (slightly less than) |
| Propane | 60 |
| Gasoline | 67 |
| Oil Sands Bitumen | 80 |

If fossil fuel users switch to less carbon-intensive fuels, the carbon dioxide emissions would be reduced. Generally this strategy would favor natural gas as the fuel with the lower carbon dioxide output. The use of natural gas also results in fewer emissions of other pollutants. Its use is being encouraged as a means of reducing urban air pollution problems.

Most users are not flexible in their fuel requirements in the short-term, although longer-term price differentials would stimulate switching. Price differentials might have to be artificially maintained. (If the market shifted to natural gas as the preferred fuel, the price of other fuels might drop.) A price drop for carbon-intensive fuels would work against efforts to discourage their use. A comprehensive assessment of the technical and economic potential for fuel switching, including an assessment of the full range of environmental consequences, is needed (Imperial Oil 1990). The full life cycle costs and benefits of fuel switching should also be assessed.

Fuel switching could be encouraged, or required, by government policies. For example, governments could convert their vehicles to natural gas or propane. Indirectly, fuel shifts could be affected by a carbon tax or an energy tax that accounts for the environmental and social impacts of different fuels.

Fuel switching could have a large effect on demand for Alberta's fossil fuels. It could reduce

Alberta's markets for coal, oil, and bitumen. For example, new power plants might be fuelled by nuclear power or renewable energy sources including biomass and hydro or possibly by natural gas. Currently, the use of natural gas as a fuel for electricity generation is discouraged in Alberta; the abundant sources of coal are used instead.

## Energy Conservation and Efficiency Options

Much can be done to encourage energy conservation. The Government of Alberta could

- require assessment of demand management options to energy requirements;
- provide low interest or interest-free loans for purchase of energy conservation devices; and
- introduce new standards for electrical lighting, appliances, building codes and vehicles.

Energy requirements can be reduced substantially with available technology, often at less cost than developing additional supplies. For example, refrigerators that reduce electricity use from the 1,200 kilowatts per year used by a typical frost-free refrigerator to 200 kilowatts per year are available. Current technology can light an office building with one-fifth of today's energy requirements. It is also possible to produce motor vehicles more than twice as efficient as those used today (Wirth 1988).

Commercially available windows, which combine spectrally selective films with insulating inert gases, achieve insulating values two to four times that of a triple pane window. The payback period for these windows in terms of energy savings is two to three years in cold climates. Hot-water-saving measures can inexpensively reduce energy use by 65 percent, with no loss of comfort. New generations of airplanes are twice as efficient as the fleets they are replacing. Recently tested models, if produced, would save a further 40 percent (Lovins 1989).

The potential energy and dollar savings of energy conservation in Alberta, achievable using technology that is available and cost effective, has been estimated at over $700 million a year, based on 1987 and 1988 prices (Zwicky 1988). As a conservative estimate, space heating energy requirements in the residential sector could be reduced about 11 percent. Alberta home owners could save as much as 16 percent of their electrical needs through improvements in home appliances.

In the commercial sector, energy-conserving technology could result in overall savings of between 18 and 29 percent. Zwicky (1988) calculated the reduction in commercial sector natural gas use at about 24 percent and the reduction in electricity use at about 13 percent.

To date, some vehicle fleets in Alberta have reduced fuel use by 40 to 50 percent using techniques such as driver training, vehicle maintenance, route planning, and new fuel-efficient vehicles. However, in calculating the overall potential energy savings, Zwicky (1988) applied a very conservative estimate of a 20 percent reduction in transportation sector fuel use.

In the industrial sector, the overall potential energy savings were estimated at 20 percent; this estimate is based on a 22 percent reduction in natural gas use and about a 9 percent reduction in electricity use.

Zwicky (1988) estimated the annual energy savings that would result from new technology and energy conservation practices as shown in the chart below.

| **Fuel** | **Annual Energy Savings** |
|---|---|
| Natural Gas | 84,636 TJ |
| Propane | 2,443 TJ |
| Refined Petroleum Products | 35,938 TJ |
| Electricity | 3,203 GWh* |

* billion watt hours

These energy savings represent

- more than the natural gas required to heat all the single-family homes in Alberta for a year;
- more than enough diesel and gasoline to fuel all the cars in Edmonton for a year; and
- as much electricity as one of the new generating units at the Genesee power plant will produce in one year.

Energy conservation and improved efficiency are, in general, the most cost-effective means of achieving these reductions. As well, electricity demand management programs must become a cornerstone of any strategy to reduce carbon dioxide emissions over the short term. Canadian industries may have the opportunity to market new energy-conserving technology, processes, and energy management services (Federal/Provincial/Territorial Task Force on Energy and the Environment 1989).

Chapter Eleven

# Mitigative Strategies: Reducing Emissions of Chlorofluorocarbons and Halons, Nitrogen Oxides, and Methane

## CHLOROFLUOROCARBONS AND HALONS

Chlorofluorocarbons (CFCs) and halons are the first of the greenhouse gases for which concrete action is being taken within a specified period as part of a global reduction strategy. Reaching agreement to reduce consumption of CFCs has been an arduous task (Roan 1989). The Montreal Protocol, signed in September 1987, set a schedule to control all substances that deplete the ozone layer. It calls for a 20 percent reduction in emissions of the five most damaging CFCs by 1995 and a reduction to 50 percent by 1999. By 1993, consumption of halons, which contain bromine or iodine instead of chlorine, is to be frozen at the 1986 level. The treaty provides for reassessing control measures at least every four years. However, CFC concentrations in the atmosphere will not be stabilized even with this protocol in effect, and there is pressure to strengthen its provisions.

Canada's per capita contribution to CFC emissions, at approximately 0.8 kilograms per year, is the second highest in the world after the United States. The pattern of use in Canada is substantially different from the global pattern, chiefly because Canada took steps to limit the use of CFCs in aerosol cans during the 1970s and more recently aerosol manufacturers voluntarily removed CFCs from their products in response to public concern.

The federal minister of environment announced a CFC control program on February 20, 1989. Since that time, the Government of Canada has put regulations in place for manufacturers of the controlled CFCs. Proposed regulations prohibit the manufacture of any halons and limit imports and exports in keeping with the Montreal Protocol. Regulations also prohibit less essential uses of CFCs and halons (Jan. 1, 1990). Included in these regulations are bans on aerosol propellant uses, food packaging uses, halon 1211 portable fire extinguishers, small CFC containers, and frivolous products. Finally, the government stated its intent to put in place a regulation to phase down the use of the controlled CFCs.

Environment Canada has stated that it is possible to phase down use of the five CFCs controlled in the protocol by 70 to 75 percent by 1995 and 95 to 98 percent by the year 2000 (Standing Committee on Environment (Nov. 7) 1989a). This phasedown is contingent on the commercial availability of hydrogenated chlorofluorocarbons (HCFCs) and hydrogenated fluorocarbons (HFCs). As well, global halon consumption could be reduced by 50 to 60 percent within five years through the judicious application of conservation measures and recovering, storing, and reusing halons.

Substitutes also exist that will facilitate a virtual phaseout of production of methyl chloroform, a chlorine compound that has recent-

ly been implicated in ozone depletion. Similarly, there are substitutes for carbon tetrachloride, another chemical with ozone-depleting properties that has many applications. The use of substitutes could limit the applications of carbon tetrachloride to use only where it is necessary for manufacturing other critical chemicals and products.

The House of Commons Standing Committee on Environment presented its report on CFCs to the House of Commons in June 1990. The committee recommended a minimum 85 percent reduction in the production and consumption of all CFCs by 1995, with a complete phaseout by 1997; a complete phaseout in the production and consumption of carbon tetrachloride and methyl chloroform by 1995 (except for their use as a feedstock for CFC and halon substitutes and as organic laboratory solvents); and a 95 percent reduction in halon production and consumption by 1993. Complete elimination of CFCs by the year 2000 was recommended, except for those essential uses where no substitute with reasonable performance is available. The committee recognized the need for CFC substitutes. But substitutes must be chosen carefully, their benefits for reducing ozone depletion assessed, and the least harmful substitute chosen.

The management of CFCs will involve many jurisdictions. The House of Commons Standing Committee recommended that the Canadian Council of Ministers of the Environment take the lead when multijurisdictional participation is required. Alberta is already working in consultation with the federal government to develop regulations and plans for the recovery, recycling, and destruction of CFCs (CASA 1990). The House of Commons Standing Committee further recommended that Environment Canada be given the necessary funds to assist in developing programs for the recovery and recycling of CFCs from commercial, household, and mobile refrigeration systems that are to be scrapped.

The accelerated timetable the committee proposed will not likely be accomplished by relying solely on market forces. Therefore, the committee recommended that a tax be levied on CFCs and halons that is at least equivalent to the one proposed for implementation in the United States. This tax would improve the attractiveness of recovery and recycling options. Furthermore, the committee recommended that funds equal to those derived from the tax be used to support initiatives that accelerate the phaseout, recovery, and destruction of CFCs and halons.

Countries party to the Montreal Protocol met in London, England in June 1990 to discuss changes to the protocol. Canada's position at that meeting was that it could phase out the consumption of controlled CFCs completely by 1997. Canada also committed itself to contribute to a fund to help developing countries obtain access to environmentally sound technology for phasing out ozone-depleting substances (Environment Canada 1990).

Environment Canada has developed a "Code of Good Practice for the Reduction of CFC Emissions in Refrigeration and Air Conditioning Systems." The code provides guidelines regarding the environmentally appropriate design, manufacture, and installation of refrigeration and air conditioning systems as well as guidelines for the handling and storage of CFCs to minimize emissions. It also specifies recovery of CFCs during servicing of these systems as well as when disposing of such equipment.

The Code of Practice will be put in place under the Canadian Environmental Protection Act (CEPA) in 1990. Environment Canada, in collaboration with the Heating, Refrigerating, and Air Conditioning Institute, is developing a promotion and training program to ensure the successful implementation of the code. If widespread voluntary implementation of the code does not occur, federal legislation is a possibility.

Environmentally acceptable technology must be available to destroy CFCs and halons as they are removed from service. Several technologies are being examined. Environment Canada is considering a test burn of halons at the Swan Hills Special Waste Treatment Facility to determine destruction efficiencies. The test will

also determine which combustion products result from incineration.

Alberta supports the complete elimination of fully halogenated CFCs by the year 2000. Strict legislation would not have a serious impact on Alberta's economy. Alberta is not a producer of CFCs and uses only about 10 percent of the CFCs used in Canada (CASA 1990). The major consumers, the companies that make foam products, have already acted to eliminate the use of the CFCs that are controlled by the Montreal Protocol. Attention will likely shift to reducing the release of those CFCs already in use.

Alberta could assist the scrap metal processing industry and the appliance service industry to develop and use technology for recovery of CFC refrigerants. Similar technology is needed for garages where automobile air conditioning units are serviced. Recovery of CFCs during the servicing of automobile air conditioners is already offered by some automotive repair centres in Ontario. Some refrigerator service centres also recover CFCs during repair. Recovered CFCs could be reused when suitable substitutes are not available. Other action that Alberta could take to recover and reuse CFCs include banning *do-it-yourself* auto air conditioner recharge canisters and eliminating halon fire extinguishing system tests.

There is also a need to investigate and encourage the development of processes and products that do not require CFCs. For example, it is possible to insulate refrigerators with vacuum panels instead of foam insulation. Work is also being done to develop domestic refrigerators cooled by helium instead of CFCs; such a system was used in the space shuttle.

## NITROGEN OXIDES

Reducing emission of oxides of nitrogen offers many benefits. It would reduce acid rain because nitrogen oxides, along with sulphur oxides, are acidic emissions that contribute to acid rain. Nitrogen oxides, in combination with volatile organic compounds (VOCs) such as gasoline and solvents, are a major cause of urban smog and elevated levels of ground-level ozone. Reduction of nitrogen oxides will reduce both problems. It would also reduce the buildup of greenhouse gases. (Nitrous oxide, one of the oxides of nitrogen, is a greenhouse gas and other oxides of nitrogen may inhibit the breakdown of atmospheric methane.)

Current Alberta standards for oxides of nitrogen from stationary sources such as compressors, when implemented for all such sources in Alberta, will reduce Alberta's emission of these gases to the point where they are in line with the requirements of international agreements.

On October 19, 1989, the Canadian Council of Ministers of the Environment (CCME) announced that the federal government would, within five years, have stringent regulations to control emissions from internal combustion engines and their fuels. Under this initiative, the volatility of gasoline was reduced for the summer months of 1990. The new regulations require that gasoline vapor emissions from gasoline distribution and marketing activities be controlled. These latter steps would reduce the release of volatile organic compounds. The actions of the CCME were based on recognition of the environmental and health problems caused by smog and ground-level ozone.

Technology applicable to new sources or suitable for retrofits does exist. For example, emissions from light duty gasoline vehicles can be reduced by a combination of improved catalysts, better air-fuel ratio control, and better control of exhaust gas recirculation. The tighter standards should not have any effect on fuel consumption.

Reduced emissions of nitrogen oxides and volatile organic compounds from on-road and off-road diesel engines and from diesel locomotive engines are also possible with current technology. There may be a slight decrease in fuel efficiency associated with the control of these emissions.

For stationary sources such as compressors and boilers, the key to emission reduction is control of fuel and air mixing. Various tech-

nologies are available to accomplish this. Some can be incorporated into the design of new boilers at no additional cost. The best practicable technology for compressor engines consists of a combination of operational adjustments and hardware additions. Addition of catalytic exhaust gas treatment systems and a shift from gas-fired compressors to electrically driven compressors are other alternatives. When considering the adoption of this new technology, planners will need to determine whether or not the changes would be economically efficient and deliver a net benefit in terms of reducing harmful emissions.

The search for clean coal technology led TransAlta Utilities to develop a low nitrogen oxide-sulphur oxide (LNS) burner under licence. This burner technology is being tested in a steam boiler used for heavy oil recovery in the Cold Lake area. The LNS burner could reduce nitrogen oxide emissions by 90 percent and sulphur oxide emissions by 80 percent at much lower cost than other technology.

Any control strategy should be carefully considered for its impact on emissions of other contaminants, especially carbon dioxide. If nitrogen oxide control results in increased energy demand per unit of output, then benefits for one environmental problem may be offset by disadvantages in another area. The most desirable actions are those that reduce overall emissions and improve energy efficiency.

## METHANE

The sources of methane are exceptionally complex and varied, and not enough is known about methane to develop comprehensive mitigative strategies. Research into how we are changing the amount of methane in the atmosphere and how the changing atmosphere influences the release of methane is needed. Such research should be combined with a comprehensive monitoring effort to assess other sources of this gas.

Preliminary studies conducted by the Alberta Environment Centre in Vegreville showed atmospheric levels of methane in Alberta to be near the global average of 1.7 ppm. Another recent study found methane production by animals, coal mining, and gas well blowouts to be very small (less than 1 percent) compared to production by wetlands (Vitt et al. 1990). This is in strong contrast to worldwide trends, where human activities account for about two-thirds of the methane produced (Rotmans et al. 1990).

Of particular importance to Alberta is a better inventory of emissions from natural gas and coal exploration, development, and processing. Once this is developed, the next step would be to develop technology that eliminates leakage of this gas wherever possible. One possibility is to capture methane from coal seams for use as a fuel gas instead of venting it to the atmosphere.

With current technology, landfills and sewage treatment plants (other important sources of methane) can be designed with systems in place to collect methane. Methane can then be used for heating or other purposes at landfill facilities or in nearby factories. This mitigative action has tie-in value; it reduces the release of methane to the atmosphere and provides an alternative to fossil fuels as energy sources.

What happens to methane in the atmosphere is connected, in part, with the atmospheric concentration of carbon monoxide and the availability of hydroxyl radicals (see Chapter Three). The conversion of carbon monoxide to carbon dioxide in the atmosphere depends on the availability of hydroxyl radicals. These same hydroxyl radicals are also involved in the breakdown of methane. Therefore, actions that reduce emissions of carbon monoxide from exhaust gases will also indirectly aid in reducing methane in the atmosphere. Because nitrogen oxides, carbon dioxide, and carbon monoxide can all be produced when fossil fuels are burned, the possibility of increased carbon monoxide production should be considered when actions to reduce emissions of nitrogen oxides and carbon dioxides are being developed.

Chapter Twelve

# Adaptive Strategies

*Adaptive strategies* are aimed at anticipating and accommodating those climate changes that cannot be avoided. "There can be a time lag of the order of decades between the emission of gases into the atmosphere and their manifestation in atmospheric and biological consequences. Past emissions have already committed planet earth to a significant warming" (Environment Canada 1988:3). Albertans would, therefore, be wise to consider steps that prepare this province for a climate different from the present one.

Adapting to a different climate is critical because natural resource industries are important to our economy; forestry, agriculture, and hunting and fishing. Tourism, a growth industry, is dependent in large part on the vegetation, and fish and wildlife resources that are among Alberta's major attractions. Alberta's scenic beauty and natural resources are also the basis for local recreational opportunities. A change in climate could bring a shift in forest distribution, changes to species distribution and agroclimatic zones, and a decrease in biological diversity.

In addition to adaptive strategies that focus on economically important natural resource industries, governments might encourage the development of climate-independent economic systems. Economic diversification, away from a dependence on oil, gas, and other natural resources, has been a goal of the Alberta government for many years. Perhaps it should receive renewed emphasis in light of the risk to natural resource industries posed by a changing climate.

## FORESTRY

Climate change is a matter of great significance to the forest industry and to forest managers. Seedlings growing in Alberta's forests won't be harvested for decades and may mature under a climate quite different from the present one. In some areas, especially along the southern edges of Alberta's forest, tree cover may be re-established. But reforestation may not be successful using current stocking practices. If commercially viable forests are the aim, reforestation must anticipate the climatic conditions 50 to 80 years or more from now. The dilemma is that some tree species that may be well-adapted to a future climate cannot be established in today's climate. Future conditions need to be accommodated in the variety of tree species, and the genetic differences within each species, used in reforestation.

The need to plan for probable climate change was recognized in recommendations of the Expert Review Panel on Forest Management in Alberta (1990). Alberta is well positioned, with its native trees to adapt to a range of future moisture and temperature conditions. Trembling aspen, which in recent years has become a major commercial species in the province, is the most widely distributed species in Canada. It may benefit substantially from increased temperature even if moisture availability remains the same. Lodgepole pine, another major commercial species in Alberta, would tolerate a warmer, drier

climate, and on some sites may even benefit from it. Practically all of Alberta's tree species would benefit from a moister, warmer climate (C. Smith: pers. comm.).

To prepare for a changing climate, increased protection of the genetic diversity that exists within forest species is needed. The Heritage Stands Protection Program could be an important part of this strategy. Protecting genetic and biological diversity is one way of keeping options open: an important part of any strategy for dealing with uncertainty.

Biological research into the most appropriate species for propagation is required. The Alberta Forest Service is gathering information on forest species that show promise for Alberta. These promising species include those traditional to the forest industry; nontraditional native species, such as black spruce and tamarack; and some exotic species, for example, red pine and green ash. This study includes information on importance and distribution, ecological setting, climatic tolerance, and vulnerability to climatic change. Some field trials are being carried out (C. Smith: pers. comm.).

Research needs to go beyond biological suitability; it needs to anticipate which tree species will be most desirable from an industry perspective in 80 years. Trembling aspen, considered a weed species 10 to 15 years ago, is now a valued species in Alberta. Is this the species on which to stake future forestry activities?

Research into the capability and suitability of different soils and different tree species is important. Research should also consider the probable increased incidence of forest pests as climate warms and focus on developing disease-resistant species. Species selection for reforestation is complex even without the added complication of potential climate change. Optimum performance on the site is affected by microclimate, soils, disease resistance, competing vegetation, and so on. Concurrently, the multiple-use objectives of the reforestation program must be considered. This includes such things as species diversity, wildlife habitats, the quality of the fibre for selected products, and so on.

The long-term viability of forestry along the southern edge of the boreal forest is another matter of concern. Should Alberta be trying to establish commercial forests along the southern edges of the boreal forest if this is the agricultural land of the future? Or should this land be the location of biomass fuel plantations or of trees grown as carbon sinks?

Plantation forests may be an energy source of the future. Massive reforestation, either to create plantation forests or to create new forests as carbon sinks, could alter local climates. Once a forest is cut small scale climate changes might make re-establishment of the forest difficult. Little is known about the local effects of reforestation. It may have a mitigating effect producing a cooler, wetter local climate.

A changed climate may also affect forest harvesting practices. In some areas, much of the harvesting currently takes place during winter when the frozen ground improves access to many areas. This practice could change if winter temperatures increase.

Climate change and altered harvesting practices have implications for the forest industry and the local and provincial economies that depend on it. Some decisions may not make economic sense in the short-term financial accounting period of most industries. The decisions that have to be made are risky. How may an industry be encouraged to restock land with species suitable not for the present climate but for a climate anticipated in 50 years? How does government decide to take certain lands out of forest production when the forest industry has been based on the concept of a stable forest land base? The associated economic, social, and technological decisions require examination within the framework of an overall strategy to deal with climate warming.

## AGRICULTURE

Similar decisions face the agriculture industry. If the climate becomes warmer and water deficits increase, certain crops will not be economically viable in some areas. Individuals will face tough decisions about what to plant, whether to plant, or whether to move and plant elsewhere. Water for irrigation could be in greater demand and shortfalls more prevalent. Here too, research is needed to understand the social and economic implications of climate change occurring over a large area.

Laboratory experiments have shown that, under increased concentrations of carbon dioxide, plants use water more efficiently and are better able to withstand drought. Elevated levels of carbon dioxide also increase the growth of most field crops. Research can help with understanding which crops and cropping practices would be appropriate under a changed and changing climate. It can answer questions such as "What are the implications of increased growth for agricultural cropping practices?" and "What will be the effects of pollutants acting together?" Knowledge and technology transfer from the central United States, where present-day climate is similar to that predicted for Alberta, might be an appropriate first step.

As Acres (1989) notes, Alberta's agriculture is relatively diverse. Therefore, adverse regional climatic conditions are unlikely to generate a precipitous drop in the economic well-being of the agricultural industry of this province.

Each year individual farmers make decisions in response to many factors; expected crop prices, input costs, soil moisture, and so on. With climate warming, the decisions of thousands of farmers will change and the face of agriculture will change, as they did with the coming of the tractor and the droughts of the 1930s. Because of the annual nature of most crops, cropping flexibility, and the long-term nature of climate change, the impact of climate change on agriculture may be incremental and accommodated fairly easily.

Individuals may, however, suffer great hardship, especially those individuals heavily capitalized in specific operations. Programs to encourage more appropriate farming practices may be warranted. In times of uncertainty, processes to encourage discussion and planning need to be established. What programs are required to lessen the hardship of adapting to the new regime? What can we learn from the lessons of the 1930s or from practices elsewhere?

Computer models predict a climate suitable for the northward expansion of agriculture. These predictions do not consider how well crops will grow on the water-logged and peaty soils of the regions that the forests of northern Alberta now cover. Research on cropping these lands is required if agriculture is to be self-sustaining in these areas.

The ability of irrigation systems to provide water under conditions of increased demand or reduced runoff also needs to be examined. The warmer climate coupled with an understandable desire to maintain the status quo in southern Alberta could lead to an increased demand for irrigation water. Additional water storage might be the answer but enlargement of the irrigation system may be inappropriate if runoff declines.

Climate models are weak in predicting regional precipitation patterns. And past precipitation records and stream flow records may not be good indicators of the future. In the absence of good quantitative information, water managers need to look at a range of possibilities extending beyond the water supply-and-demand scenarios indicated by historical records. A broad perspective is critical for planning capital works and responding to demands for more water.

One aspect of water management that might be examined is the feasibility of interbasin transfer from northern Alberta to southern Alberta. But

strategies that encourage agricultural practices that are most appropriate to the climate limitations of the area should also be considered. The management of water, like the management of all resources, should be studied in the context of the long-term future of Alberta under a changed climate.

## BIOLOGICAL DIVERSITY

Changes in precipitation patterns may be more important than temperature in determining species distribution and diversity. Under a changing climate, plant and animal species will be severely stressed, particularly at the edges of their ranges where environmental factors already limit distribution.

If biological diversity is to be preserved, representative areas of Alberta's ecosystems may need better protection. These areas need to be connected to facilitate movement by species to new areas of suitable habitat if present areas become uninhabitable. To protect the necessary areas, a greater emphasis on the climatic criteria for designating parks and other reserves may be needed. According to the Endangered Spaces campaign being conducted by World Wildlife Fund Canada and the Canadian Parks and Wilderness Society (Hummel 1989), Canada does not adequately protect its ecosystems.

## Chapter Thirteen

# Economic Instruments

The use of market-based, economic instruments may lead to a quicker resolution of environmental problems than the traditional method of regulation. Market-based approaches can provide firms with incentives to reduce emissions below permitted levels and to develop new technology to do so. Several tools are available, including taxes, subsidies, and emission charges.

## CARBON TAXES

A carbon tax based on the carbon content of fossil fuels has been proposed (Jessup 1989). The tax would not be applied to the carbon dioxide emissions from biomass, wood, or renewable energy sources providing they are managed sustainably (Goreau 1990). Instead, a carbon tax would be designed to encourage the use of renewable energy sources, more use of cleaner burning fuels that emit less carbon dioxide, or improvements in fuel efficiencies. Because of the differences in carbon-to-energy ratios for different fossil fuels, a carbon tax would be approximately twice as high on coal as a similar tax on natural gas. Oil would be taxed at an intermediate level.

If a carbon tax were applied at the well head or mine mouth, it would mean that any energy used in a product's manufacture would be reflected in the total tax on the finished product or service. This would encourage the use of energy-efficient technology at all stages in a product's life cycle and not only at the point of use. A carbon tax would encourage a shift to less carbon-intensive fuels or to renewable energy sources. For example, it would favor methanol produced from grain over that produced by reforming natural gas. It would also favor production of gasoline from conventional oil over that produced from oil sands. A carbon tax would favor hydroelectric and nuclear energy because neither source is a major contributor of carbon dioxide emissions.

Taxes might also be levied directly on consumer products. Energy-consuming provinces such as Ontario are discussing a tax on fuel consumption. For example, transportation fuels might be taxed. These taxes would be designed to achieve specific objectives such as reducing consumption of gasoline. The resulting increase in fuel prices may reduce travel or enhance the desirability of smaller vehicles.

To influence the fuel choice and energy efficiency of the manufacturing sector, a tax might be applied on fuels used in processing and manufacturing.

Tax revenues could be used to support development of renewable energy sources, conservation, efficiency improvements, and reforestation. Tax credits or offsets could be a means of encouraging projects that store carbon dioxide or replace fossil fuels. The additional tax would make many products more expensive and adjustments might be needed to assist lower income groups. To alter energy use patterns substantially, the carbon tax might need to double energy prices.

Fossil fuel resource companies have raised concerns that a carbon tax would increase the price of exported coal, oil, and gas and have asked whether it could be applied to energy imports.

Taxing fossil fuels would give preference to renewable energy sources but these are not

without environmental impacts. As a result, an energy tax has been suggested as an alternative to a carbon tax. This tax would apply to all energy sources including nuclear energy and provide a more level playing field for suppliers.

## SUBSIDIES

Subsidies or incentives can be provided to encourage the desired industrial development or energy use patterns that would not otherwise be feasible. They may be used for a number of reasons, for example; job creation, regional development, or energy security. Removal of subsidies would allow energy developments to compete based on their own merits. The Standing Committee on Energy, Mines, and Resources (1990) points out that the issue of equity or "a level playing field" is an incredibly complex one. Nevertheless, it recommended that the federal government promote a more equitable balance in its support, regulation, and taxation of various energy sectors.

## TRADABLE PERMITS

Market-based approaches, such as tradable permits, may encourage effective and economically efficient emission reductions (Moore et al. 1989; National Economic Research Associates, Inc. 1990) by providing firms with incentives to reduce emissions below permitted levels (Standing Committee on Energy, Mines, and Resources 1990). These permits offer the potential of reducing the cost of complying with emission limits.

With tradable permit systems, the government sets a total level of emissions, issues or sells emission-level permits, then allows firms to sell or trade permits among themselves. Sources with low emission control costs may thus be encouraged to reduce their emissions more than they otherwise would. They could then sell their excess emission permits to companies that have high emission control costs. The desired level of emission reduction could thus be achieved at a lower cost than if each company reduced its emissions by a fixed amount. Tradable permits can be combined with standards for maximum emissions to protect the environment. And over time, total emissions can be reduced by cutting the number of permits.

Tradable permits are to be used by the United States government in phasing down the use of CFCs (National Economic Research Associates, Inc. 1990). Equivalencies among the five regulated CFCs and their substitutes have been developed to encourage producers to shift consumption of CFCs to those with less potential for depleting stratospheric ozone. As consumption of the more harmful CFCs is reduced, producers gain credits that may be traded with other producers who have not yet reduced their use of CFCs.

Energy, Mines, and Resources Canada (1990) suggested that the use of tradable permits for automotive fuel efficiency be studied. Under this system, manufacturers who do better than the fleet fuel efficiency average would be permitted to sell their excess credits or permits to other manufacturers.

If tradable permits were to be used to manage emissions of greenhouse gases, the system would require the development of climate warming potential equivalencies among the various gases to ensure that reduction of emissions of one gas does not result in a net increase in another gas. If all atmospheric emissions, including sulphur dioxide, and nitrogen oxides and volatile organic compounds are considered, the matter becomes much more complex. The different environmental impacts of the gases would all need to be considered.

A full assessment of the economic, environmental, and social implications of carbon taxes (Kuras and Kelly 1989), energy taxes (Pembina Institute 1990), and other options has been recommended (Imperial Oil 1990; Canadian Petroleum Association 1990).

# Final Comments

Greenhouse gases cause the atmosphere to heat by about 35 degrees Celsius, making the earth a habitable place. Human activities are, however, interfering with the natural balance and cycling of elements in significant ways. As a result, concentrations of carbon dioxide, nitrous oxide, methane, and other greenhouse gases in the atmosphere are rapidly rising above normal levels. Recently created chemicals such as chlorofluorocarbons are also accumulating in the atmosphere.

At increased concentrations in the atmosphere the same greenhouse gases that are responsible for natural greenhouse warming are considered to be atmospheric pollutants. They could cause average air temperatures near the earth's surface to increase three degrees Celsius by the year 2030. If such global warming occurs, scientists expect it to have some negative effects on the environment and ultimately on human well-being. However, the recent climate and other environmental changes that have been observed cannot, with certainty, be attributed to the greenhouse effect.

Given the scientific uncertainty surrounding global warming, what, if anything, should be done? While most individuals are aware of times when, through foolish persistence, they have brought some anticipated misfortune on themselves, they are becoming increasingly aware that current environmental threats are the result of inappropriate human behavior. In terms of global warming, current patterns of human interaction with the environment are overwhelming the atmosphere with pollutants; these patterns must be reversed if the misfortunes of global warming are to be avoided.

Thus far, the industrialized countries of the world are most responsible for polluting the atmosphere. Developing regions will become major contributors to pollution in the years ahead. The transfer of pollution-reducing technology and research to developing countries would help reduce the environmental impacts of their industrialization process. Financial support for environmentally sound development in these regions may also be necessary.

To ensure that such development is encouraged and maintained, greater cooperation among governments at every level of jurisdiction is essential. Major international efforts are underway to stabilize concentrations of carbon dioxide in the atmosphere, but formal agreements have not been signed. The Montreal Protocol on ozone depleting substances does allow room for optimism about the prospects for more international cooperation.

Several initiatives that are designed to prevent more greenhouse warming are discussed in this paper, but the list of options is not exhaustive. Choices that will help avoid polluting the environment are not always simple to make. Among the many variables that make environmental choices difficult is the reality that pollutants interact in complex ways that are not fully understood. Therefore, decisions about which pollution-reduction strategies to follow must be carefully considered, and strategy implementation must be well planned to help ensure that the end results are desirable.

Research into pollution sources and abatement and the workings of climate systems will continue. But more than research is required. Prudence dictates that action be taken now to reduce the global emission of pollutants. The potential consequences of global warming are too severe to justify inaction. Fortunately, many of the actions to mitigate (soften) the greenhouse effect have economic and other environmental advantages and would reduce the need for costly adaptive responses in the event of climate change.

Strategies for adapting to global warming are receiving less attention than mitigative strategies. Further work on them is advisable because pollutants already put into the atmosphere probably have committed the earth to some global warming.

Ultimately, the key to responding effectively to the challenge of global warming is recognizing that each human being is responsible in a small way for the problem *and for the solution.* Though industries can be identified as major pollution sources, most consumers demand the products created by industry and expect to continue enjoying the benefits of these products at low cost. Consumers must, therefore, accept some of the responsibility for pollution and be aware that expectations will likely have to change if the world's natural systems are to be restored to good health.

Swifter, more effective solutions will be found if individuals make their environmental preferences known and dovetail their responsibilities with industry and government. In a democratic society what most individuals *want* and what governments *do* should be congruent. Governments can ensure that the right mechanisms are in place to effect the environmental goals of their constituents.

There are opportunities for individual Albertans to work with their governments to clean up the environment. *Climate Warming? Exploring the Answers* provides some basic information about climate change and related environmental, political, and economic issues. With this information readers can take full advantage of opportunities to have a say in the development of strategies for managing greenhouse gases and associated climate change.

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